6

Illustrated World of Science Encyclopedia

Earth Science III:
THE ARRIVAL
OF MAN

THE WORLD OF SCIENCE

THE WORLD OF SCIENCE

VOLUME

6

EARTH SCIENCE III

The Arrival of Man

with

The Illustrated Science Dictionary

CREATIVE WORLD PUBLICATIONS, INC.

CHICAGO

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VOLUME 6

EARTH SCIENCE III
The Arrival of Man

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The Arrival of Man

INTRODUCTION

This volume records the exciting developments in the evolution of life from the latter part of the Mesozoic era (about 130 million years ago) up to modern times. After millions of years of slow but steady evolutionary advance, life on the Earth began to change and to diversify at a faster and faster pace.

More than 350 million years ago, in the Devonian period, the sprawling stegocephalian amphibians successfully invaded the land. This was a profound step, for it meant that the vertebrates, animals with backbones, were entering an entirely new environment, thus opening many avenues for evolution over a tremendous range of adaptation. This volume describes many of these lines of evolution, particularly as they took place during the closing period of the Mesozoic and the entire Cenozoic era, when mammals finally emerged as the dominant form of life on the land.

This volume, in addition to tracing the explosive development of the vertebrates, in a parallel manner describes the setting in which these changes took place. During the time in which these dramatic events were transpiring, mountains were built up by the forces within the Earth and then relentlessly eroded by the action of wind and water. Landmasses slowly moved apart, while the seas invaded other landmasses. During this time, every feature of the present-day landscape was formed; the Alps and Himalayas rose from the sea floor; the American cordilleras and all the other mountains of the Earth rose to their present heights; the rivers attained the courses they now follow; and the climatic zones of the Earth, after a time of widespread glaciation, took on their modern character.

The forests of the Earth faithfully recorded the changes in climatic and geographic conditions with the development and spread of the angiosperms, or flowering trees, and the conifers.

With the close of the Cretaceous period, the dinosaurs and others of the reptilian orders became extinct. Before they vanished, however, perhaps as early as the Jurassic period, some highly developed members of their group evolved into the first known bird, *Archaeopteryx*, and into the first primitive mammalian forms.

Beginning with the early epochs of the Tertiary period, the development and diversification of the mammalian groups reached extraordinary levels. They seemed to thrive in every environment—in cold and heat, on land, in water, and, to a lesser extent, in the air. So well did the mammals adapt to their surroundings that one representative group, the whales, soon became the largest animals ever to have lived—even exceeding the great dinosaurs in size.

Several different sections of Volume 6 describe in some detail the different lines of evolution followed by the mammals. The eutherians (or placental mammals) and marsupials developed early in the new evolutionary trend. The latter followed amazing lines of development in South America and Australia. Some marsupials, in fact, reached the size of present-day oxen, and others such as *Thylacosmilus*, which resembled the saber-toothed tigers, were ferocious carnivores. These animals lacked the intelligence of the placental mammals, however, and soon gave way to such groups as the Carnivora; the Proboscidea, which include the mammoths, mastodonts, and elephants; the Perissodactyla, or odd-toed hoofed mammals, such as rhinoceroses and horses; the Artiodactyls, the even-toed hoofed mammals that include the deer, pigs, giraffes, camels, goats, sheep, and cattle; and finally the Primates, which include the lemurs, monkeys, apes, and men. Many hundreds of millions of years had been required, but living organisms had made enormous advances.

The final part of Volume 6 describes some of man's activities, particularly as they relate to the exploration of that vast frontier, the ocean. Although scientists have been studying landmasses for many years, relatively little is known about what lies beneath the surface; and even less is known about the vast ocean basins. Scientists are making many new discoveries about the oceans and their depths. This volume will help readers understand and appreciate the importance of that work.

MAURICE E. BIGGS
Head, Geophysics Section
and Assistant State Geologist,
Indiana Geological Survey

THE REPTILES | their evolution and classification

SEYMOURIA BEYLORENSIS — This animal is difficult to classify because it exhibits some characteristics of amphibian's and some characteristics of reptiles.

For many people, the sight of a reptile, especially a snake, often arouses disgust or fright. No amount of reasoning can overcome their conviction that the animal—whether it is a harmless garter snake or an admittedly menacing cobra—poses some insidious, evil danger.

In defense of people who fear reptiles, it is only fair to recall that many ancient religions and a few now in existence have allegedly invested the snake or serpent with evil powers combined with supernatural wisdom. Small wonder, then, that some individuals consciously or subconsciously decide that discretion is the better part of valor—and take flight at the glimpse of a snake.

Putting aside the myths and symbolism that have enveloped the reptiles through the ages, scientific research has produced a relatively thorough knowledge of these sometimes beautiful animals. The research has uncovered a great deal of information about how these animals developed in the remote past and about how they live in the present day.

FROM AMPHIBIAN TO REPTILE

In evolutionary terms, the reptiles advanced one step beyond the amphibians by freeing themselves from dependence on an aquatic environment. The advancement occurred largely through the development of the amniote egg, within which an embryo can develop in a protected environment on land without proceeding through intermediate larval stages.

The egg of a reptile has a tough but porous outer shell that is more or less mineralized and permeable to air. Within the shell, the embryo is immersed in a watery fluid that is enveloped by a membranous sac called an amnion. The embryo is attached to the yolk sac, which contains nutritive substances, and to the allantois, which regulates exchanges with the outer environment.

The first appearance of the amniote egg, therefore, serves to indicate the appearance of the class Reptilia. Very few amniote eggs dating from remote periods have been discovered; the most ancient specimen comes from early Permian strata in Texas. Consequently, the reptiles must have existed at least 250 million years ago.

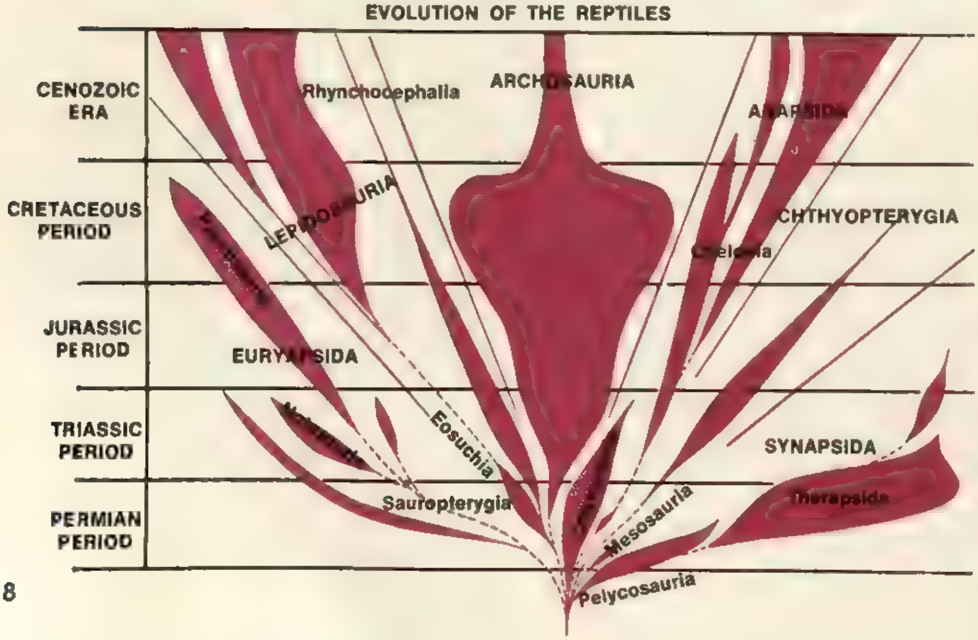
The discovery of fossil eggs in Permian formations has not shed any light on the processes of evolution or the origin of the reptiles as a class. To gain an understanding of these matters, paleontologists look to the skeletal remains of terrestrial vertebrates existing during the early Permian period. By studying the bone characteristics of numerous fossils, they have traced the derivation of the reptiles from the labyrinthodonts (amphibians of the Carboniferous), and they have determined that the genera transitional between amphibians and reptiles appeared during the Permian. On the basis of fossil studies, the complex evolutionary history of the reptiles has been reconstructed.

The Reptilia developed so greatly during the Mesozoic era that the era has become popularly known as the Era of Reptiles or the Age of Reptiles. Moreover, during the Mesozoic era, the reptiles evolved further into two new classes, Aves (birds) and Mammalia (mammals). During the Cenozoic era, which followed the Mesozoic, the reptiles declined tremendously in number; as a consequence, in comparison with its once dominant position, the class is now represented by a limited number of species.

THE SEYMOURIAMORPHS

In the evolutionary developme... rom amphibians to reptiles, a large r... was played by animals belonging to ... der

EVOLUTION OF THE REPTILES



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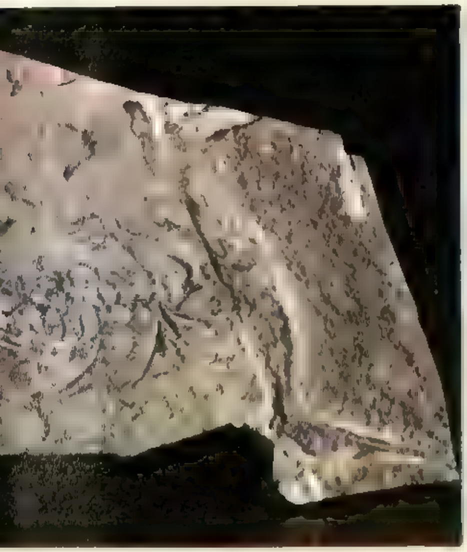
a

b

THE ANAPSIDA—The development of the Anapsida probably began during the late Carboniferous or early Permian. *Labidosaurus*, *Captorhinus*, and *Limnoscelis*—three of the oldest known reptiles—belong to the order Cotylosauria, a division of this subclass. The Cotylosauria also included several families that adapted to life on land, sometimes in very dry climates. The Cotylosauria became extinct during the Triassic period.

Another order that appeared very early and became extinct near the end of the Permian

Seymouriamorpha. The name of this order is derived from the generic name of an animal that lived in the southwestern part of the United States during the early Permian period. This animal, *Seymouria*, is generally considered to be a predecessor of the reptiles, representing a transitional stage between the labyrinthodont amphibians and the reptiles.



period was the order Mesosauria, which ordinarily is classified under the subclass Parapsida. Fossils of these small swimming reptiles have been discovered in both South America and South Africa. Illustration 3a shows a fossil of *Mesosaurus brasiliensis*.

Another order of Anapsida appeared during the Triassic. This was the order Chelonia, whose members (turtles and tortoises) constitute the only living anapsids. Illustration 3b shows the shell of *Emys nicolisi*, a primitive tortoise.

THE LEPIDOSAURIA—The order Eosuchia of the subclass Lepidosauria appeared as early as the Permian period; representatives of this order were small lizardlike reptiles. They became extinct during the Triassic, but probably were the ancestors of the order Squamata, the most flourishing group of reptiles living at the present time. The first representatives of Squamata appeared in the Jurassic and later evolved into the lizards, iguanas, Varanidae, and other saurians. Some genera were well adapted to aquatic environs. The *Mosasaurus*, which attained a length of about 5.5 m (about 18 ft), was an aquatic form. The snakes, which comprise a suborder (Serpentes) of Squamata, did not appear until the late Cretaceous period.

Rhynchocephia, the third order of Lepidosauria, derived from the Eosuchia during the Triassic and developed freely until midway through the Cretaceous, after which it declined. The only living representative of the order is the *Sphenodon ortuatara* (shown here), a small reptile living on a few islands near New Zealand.

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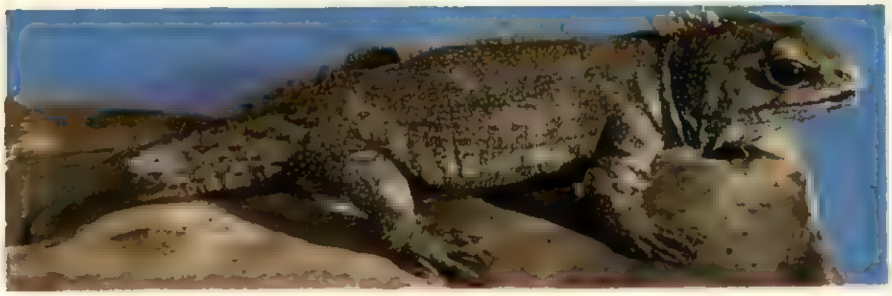

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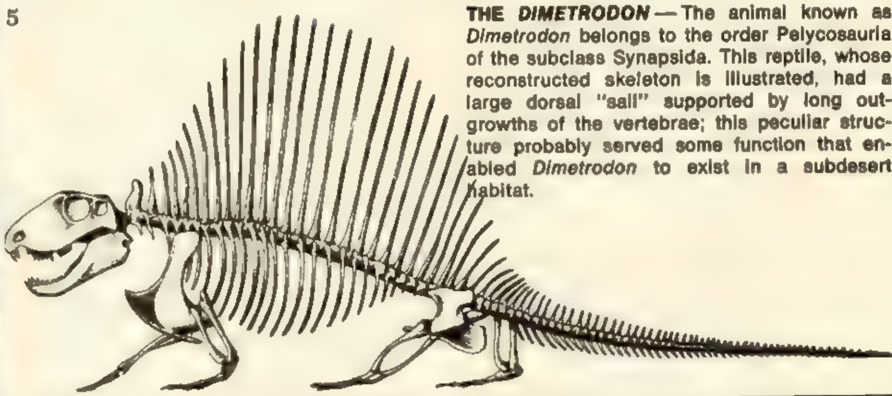
THE *DIMETRODON*—The animal known as *Dimetrodon* belongs to the order Pelycosauria of the subclass Synapsida. This reptile, whose reconstructed skeleton is illustrated, had a large dorsal "sail" supported by long outgrowths of the vertebrae; this peculiar structure probably served some function that enabled *Dimetrodon* to exist in a subdesert habitat.



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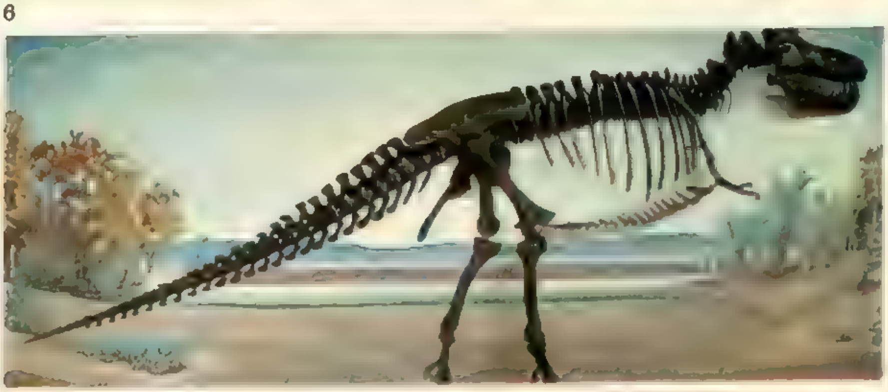


A REPRESENTATIVE OF THE ARCHOSAURIA—This illustration is a representation of the skeleton of a highly evolved archosaur, *Tyrannosaurus rex*, a dinosaur that flourished during the late Cretaceous period. The subclass Archosauria originated in the early Triassic; it may be considered the most important group of reptiles throughout the Mesozoic era. The earliest archosaurs, members of the order Thecodontia, were the ancestors of the present-day crocodiles and the extinct dinosaurs; the former were derived through the order Crocodilia; the latter through two orders, Saurischia and Ornithischia. The thecodonts became extinct before the end of the Triassic, while the crocodilians continue to flourish. The saurischian dinosaurs developed throughout the entire Mesozoic era, evolving tremendously during the Jurassic and culminating in such enormous animals as *Tyrannosaurus* before becoming extinct at the end of the Cretaceous. The ornithischians existed throughout the Mesozoic also, but they experienced their greatest development during the Cretaceous, just prior to becoming extinct. Another order of archosaurs, the Pterosauria (flying reptiles), also evolved during the Jurassic and died out in the Cretaceous.

Seymouria was a four-footed animal about 49 to 61 cm (20–24 in.) long. It had a flat roofed skull with otic notches for the upper part of the eardrum (as in some labyrinthodonts); the arrangement of bones in the skull was very much like that found in amphibians. Its teeth, too, were quite similar to those of the labyrinthodonts. Indeed, the entire skull of *Seymouria* was almost identical with the skulls of primitive amphibians.

Why, then, has *Seymouria* been classified by many authorities as an ancestor of the reptiles? It is because the remaining parts of the skeleton closely resemble reptilian structures. Particularly similar are the vertebrae, with laterally extending neural arches; the shoulder girdle, with the interclavicle showing a wide median sinus (found in the first true reptiles); a greatly extended ilium with a second vertebra incorporated into the sacrum, as in reptiles (which thus have two sacral vertebrae instead of a single vertebra as found in amphibians); and a number of phalanges equal to that found in reptiles.

Whether *Seymouria* was an amphibian or a reptile remains controversial. This animal would be considered a reptile without question if it were known that it produced amniote eggs—but unfortunately no fossil eggs of *Seymouria* have ever been discovered. Nevertheless, the animal occupies an extremely important position in the evolutionary history of vertebrates because it demonstrates the presence of transitional forms between the two great classes, Amphibia and Reptilia, and shows how these forms can overlap in time. The fact that highly evolved and specialized reptiles are known to have existed during the same time span indicates that reptiles evolved from labyrinthodonts prior to the Permian period. In other words, the Seymouriamorpha and the Reptilia probably evolved from a common ancestor.

EVOLUTION OF THE REPTILES

As previously indicated, the reptiles probably evolved from the amphibians during the latter part of the Carboniferous, a fact attested to by the discovery of reptilian fossils in Carboniferous deposits in North America and western Europe. The abundant fossil remains found in Permian strata indicate that the reptiles were well on their way toward the evolutionary explosion that occurred during the Mesozoic era, a time when the reptiles dominated the animal world.

Throughout the Mesozoic—from the Triassic period through the Cretaceous—reptiles were the most highly evolved and powerful animals on the Earth. During this era, the amphibians declined considerably; today they constitute a small group, with relatively few forms, inhabiting lakes and swamps. The reptiles, on the other hand, remained preeminent until the end of the Cretaceous, when they declined rapidly, and the mammals began their startling development.

In considering the reptiles of the Permian period, it is well to recall an evolutionary law formulated by the American paleontologist Henry Fairfield Osborn: "When a given group of organisms, originally living in a single environment, becomes the dominant group in that environment, the group tends to expand into and adapt itself to every environment." In accordance with this law, the reptiles, having become dominant on the land, also developed forms adapted to fresh water, to the sea, and even to the air. Later, during the Cenozoic, the mammals pursued a similar evolutionary course, producing forms adapted to life in the sea (whales, porpoises, dolphins, seals, sea lions, walruses, and sea cows), as well as forms adapted for flying (bats).

CLASSIFICATION OF THE REPTILES

The class Reptilia ordinarily is divided into the following six subclasses, each of which is further subdivided into orders and families: Anapsida, Synapsida, Parapsida, Euryapsida, Lepidosauria, and Archosauria. Of these subclasses, three are extinct, while three have some living representatives.

7

CHELONIA—By some standards, [illegible] elonians are the most grotesque of al[illegible] ptiles —and the least changeable. The[illegible] tures have remained relatively unaltere[illegible] ghout their long history. The chief char[illegible] ics of members of the order Chelonia [illegible] bony shields that cover their bodies, [illegible] g the carapace (Illustration 7a) on the [illegible] d the ventral plastron (Illustration 7b) [illegible] belly. The carapace consists of verteb[illegible] s, extending down the middle and form[illegible] n dorsal vertebrae joined together and [illegible] plates on either side of the vertebral pla[illegible] lying flush with them to comprise the [illegible] addition, the nuchal or neck plate is si[illegible] at the front of the carapace, and the [illegible] ate is located at the rear; plates arou[illegible] edge bind the carapace to the ventral pl[illegible] which in turn is made up of nine plates.

A layer of horny plates of epi[illegible] origin covers the carapace and often [illegible] stron, but these plates do not corres[illegible] o the arrangement of the bony plates [illegible] are not preserved in the fossil state. The [illegible] fication of fossil specimens of the orde[illegible] elonia, therefore, is based principally [illegible] bony plates, the parts of the skeleto[illegible] at have undergone the few changes duri[illegible] evolution of the group. The skull, wh[illegible] lso of some importance in classificatio[illegible] of the anapsid type; it lacks teeth, but [illegible] a very strong, horny beak.

The most ancient specimens of [illegible] helonia date from Triassic times. Althou[illegible] lonians changed little, at one time they [illegible] ssed a far more primitive skull than the [illegible] ent-day representatives, and they had tee[illegible] e head and tail were not retractable, an[illegible] pelvic bone was joined to the carapace [illegible] ventral plastron. This group is placed in [illegible] border Proganochelydia, of which *Prog[illegible]elys* or *Triassochelys* is the best-known re[illegible]ntative.

Most of the tortoises of the J[illegible]sic and Cretaceous periods were slightly [illegible] highly evolved than the Triassic chelon[illegible] having lost all signs of teeth. Assigned [illegible] he suborder Amphichelydia, these tortoise[illegible] were terrestrial animals, and their heads were not retractable. Members of this suborder survived until the Pliocene epoch of the Tertiary period.

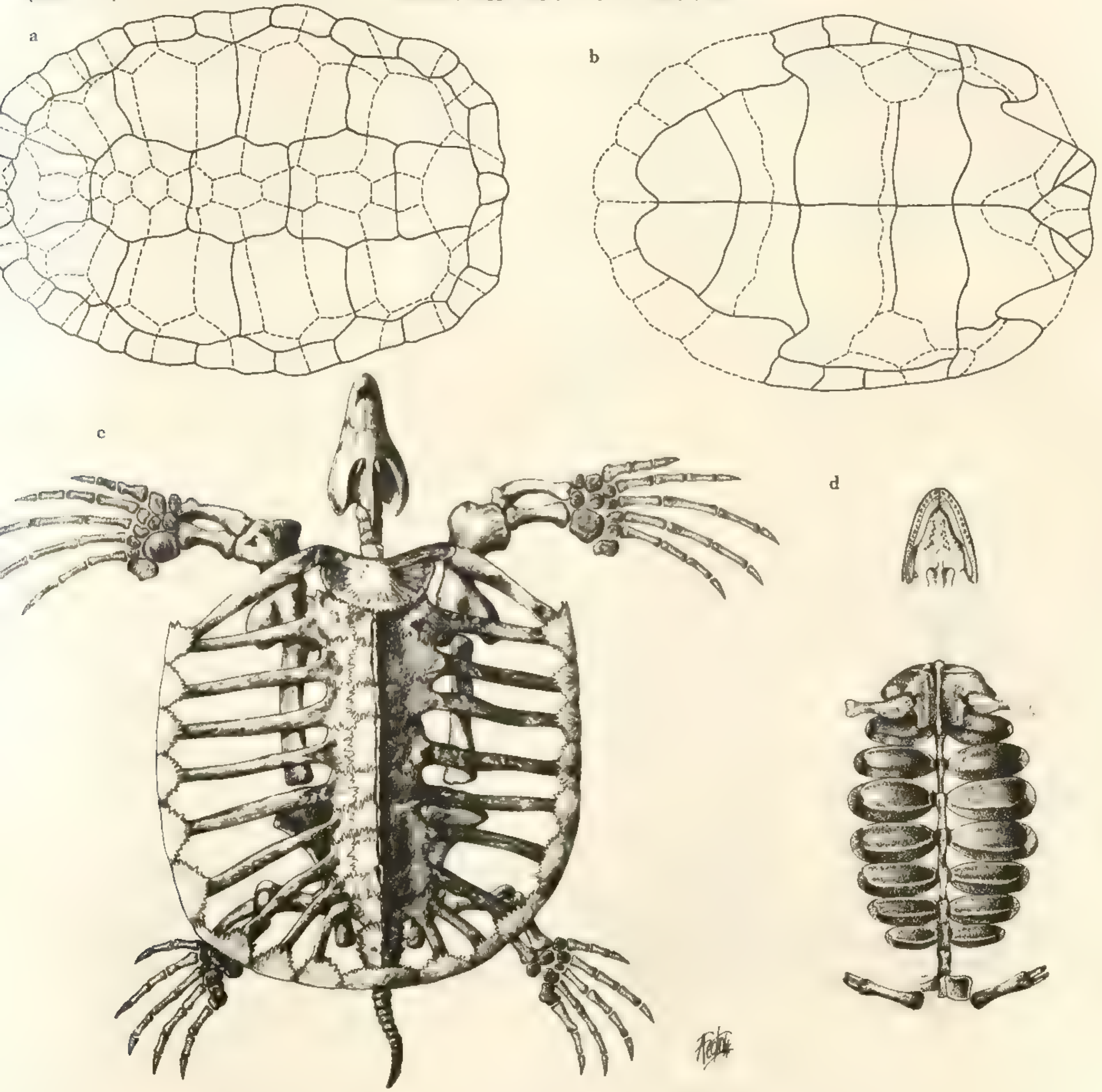
The relatively more advanced representatives of the suborder Pleurodira appeared during the second half of the Cretaceous period, and are still living today in South America and Madagascar. They are distinguished chiefly by their ability to draw their heads inside their shells by means of a simple lateral folding of the neck.

The most highly evolved suborder is Cryptodira, members of which possess an ingenious accordionlike mechanism by which the head may be quickly and easily drawn inside the protective shell. Most of the living turtles and tortoises belong to this suborder.

The cryptodires appeared during the Upper Cretaceous. During the same epoch, cryptodires of the family Protostegidae invaded the seas; the Protostegidae were similar to the

modern marine turtles, which belong to the family Cheloniidae. Typical of the Protostegidae was *Archelon* (whose skeleton is shown in illustration 7c); this giant marine turtle of Cretaceous times grew to a length of 3.5 m (about 11 ft).

The origin of the chelonians is somewhat disputed. Some authorities place it in the Middle Permian, from which dates *Euntosaurus* (illustration 7d), discovered in South Africa. The ribs of this animal were enlarged and flattened, suggesting perhaps an early phase of armor plating. However, the skull of the one specimen discovered is insufficiently preserved for scientists to relate the animal to the first chelonian of the Triassic.



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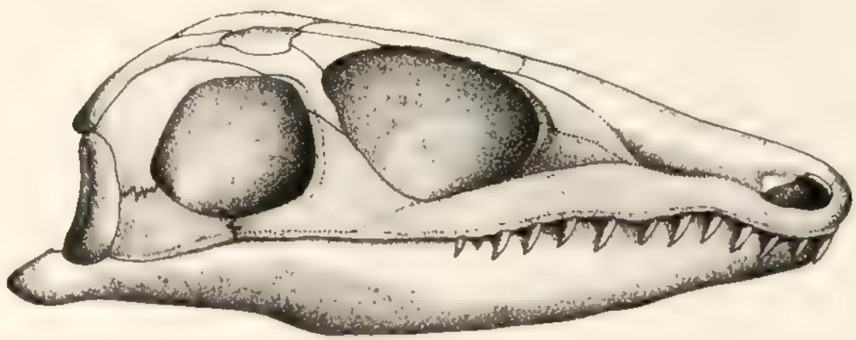


THE EOSUCHIA—The oldest and most primitive reptiles with diapsid skulls—that is, having two apertures at the temples—belong to the order Eosuchia of the subclass Lepidosauria. The eosuchians were lizard-shaped animals that inhabited Africa and Madagascar during the Permian and Triassic periods. They had long, tapering skulls with teeth located around the edge of the jaw and in the palate. In all likelihood, they were the ancestors of present-day lizards.

The illustration depicts the skull of *Youngina*, the earliest diapsid reptile yet discovered; this fossil was found in an Upper Permian deposit in South Africa.

The subclass Anapsida, which includes the most ancient and primitive species, consists of reptiles with roofed skulls similar to the skulls of amphibians. The subclass is divided into two orders, the extinct Cotylosauria and the Chelonia, the latter a large group that has remained more or less intact from Triassic times to the present.

The subclass Lepidosauria is subdivided into three orders. Eosuchia, comprising a variety of small reptiles with lizardlike bodies, is an extinct order; members of this order are considered to have been the progenitors of the present-day Squamata. The order Rhynchocephia includes the tuatara and its fossil relatives. Squamata is the order encompassing all the families of lizards and snakes.

The subclass Archosauria consists of five orders, only one of which, Crocodilia, has any living representatives. The archosaurs dominated the land fauna of the Mesozoic period.

MESOSAURIA

The order Mesosauria, subclass Parapsida, is composed of small lizard-shaped aquatic reptiles that varied in length from 30 to 60 cm (about 12 to 24 in.). Representatives of this extinct order inhabited freshwater inland lakes. They have been identified frequently with Permian deposits in South America and South Africa. They were the first reptiles to live in an aquatic environment, and their skeletal structure suggests that they were well adapted for swimming. Quite likely their pedal digits were joined together by a thin membranous web. They had elongated skulls, and their mouths were equipped with many needle-sharp teeth.

The only known member of this group is assigned the generic name *Mesosaurus*. The distribution of *Mesosaurus* serves as one substantiation of Wegener's theory of continental drift, which holds that South America and Africa were joined together during the Perm... period. Obviously, the mesosaurs, ... pletely landlocked in inland waters, ... ld not possibly have crossed the sea ... eached areas in which they are belie... o have been widespread.

OTHER EXTINCT REPTI...

The Synapsida are known a... ammal-like reptiles. They had a sin... opening in the skull below the squ... sal and postorbital bones. Pelycosaur... n order that ran through its life span ... the late Carboniferous and early Per... n time, were elongated reptiles. Som... veloped long bony projections from th... ertebrae that probably supported a lar... sail-like membrane. The Therapsida, ... second group of synapsids, arose in t... Permian period. After diverging into ... nivorous and herbivorous forms, the... adually acquired mammalian chara... stics of dentition and limb orientatio... ring the Triassic. In the Jurassic pe... , which followed, the therapsids we... eplaced by mammals that evidently d... ed from the therapsids.

Euryapsida, the subclass o... nct reptiles that had a skull openin... ove the squamosal and postorbital ... nes, included amphibious, aquatic, ... terrestrial groups. Protosauria, w... h were the terrestrial forms, first appeared in the Permian period and persisted through the Triassic. Some were quite small, but one protosaur, *Tanystropheus*, was about 1 m (about 3 ft) long. It had a slender neck that made up almost half the creature's length, a short body, and limbs and tail of comparatively normal proportions. The protosaurs gave rise to the order Sauropterygia, which consisted of three suborders: the aquatic Nothosauria, Plesiosauria, and Placodontia. The limbs of the nothosaurs and placodonts probably could have been used for walking; but the plesiosaurs, which had paddlelike limbs, most likely never came ashore.

THE SHAPE OF THE EARTH | artificial satellites provide the answer

At first sight, the subject of the Earth's shape may seem neither complex nor interesting. Yet the shape of the Earth has enabled scientists to understand the structure of the continental masses and their possible movements.

TWO THOUSAND YEARS OF MEASUREMENT

Before early man could begin to measure the Earth, it was clearly necessary he should know that it was spherical in shape. A primitive man who left his own region to go hunting, and found himself in one new landscape after another, must have wondered if the Earth had any limits at all. The Greeks and the Egyptians, however, noticed that the height of celestial bodies above the horizon varied according to the spot on the Earth's surface from which they were seen, and realized from this that the Earth was spherical. The first measurement of the Earth's diameter known to history was made about 250 B.C. by an Alexandrian Greek, Eratosthenes, who based his estimate on the knowledge of π and the supposition that the Earth was perfectly spherical.

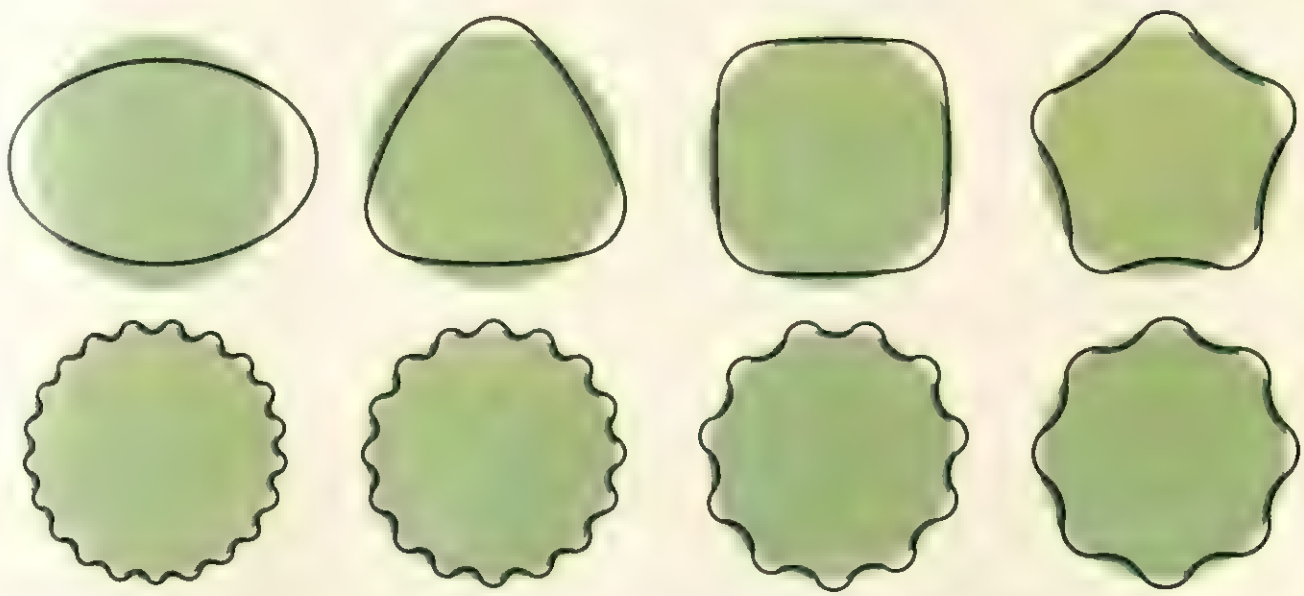
Eratosthenes' principle of measurement was not improved until the eighteenth century. His principle was used by the Greek mathematician Poseidonius and by the Arab astronomers of the first millennium A.D. Even today the principle can still be used to work out the Earth's shape, using a system of measurements calculated almost in their present form as far back as the seventeenth century.

Toward the end of the seventeenth century it was realized that the Earth was not perfectly spherical, but ellipsoid. This new idea opened the way for many studies, of which Newton's was the most important. An entire new series of measurements was made to determine the exact extent of the flattening of the Earth at the poles. This flattening causes almost imperceptible variations in measurements of the Earth, which for this reason are extremely difficult to make.

The earliest measurements of polar flattening led to the belief that the Earth's ellipsoid was elongated rather than flattened: that is, flattened at the equator rather than at the poles. Later, when more modern methods of measurement were employed, it was possible not only to determine the exact amount of the polar flattening, but also to learn more about the shape of the Earth in general. Careful measurements made by America's Vanguard I satellite during the International Geophysical Year (1957-58) revealed that the term "ellipsoid" was an approximation, and that the Earth in fact has a tendency to be pear-shaped.

The use of artificial satellites has made it possible to gain extremely accurate knowledge of the Earth's shape. The measurements these satellites make are indirect ones, in that they determine the irregularities of the Earth's gravity. (The pull of gravity varies from place to place.) From these, the exact shape of the planet has been calculated.

1



MEASUREMENT BY HARMONICS—The study of satellite orbits reveals deformations of the Earth's shape that are even more complex than those of the ellipsoid or the pear shape. Analysis of the Earth's shape and the orbits of satellites is made by a method derived from the Fourier series: that is, by a description of the contribution to the Earth's shape of each of the sinusoidal lines that can be traced across it.

Each of these components is named according to the number of undulations of the sinusoid with respect to the center of the sphere on whose surface it is traced.

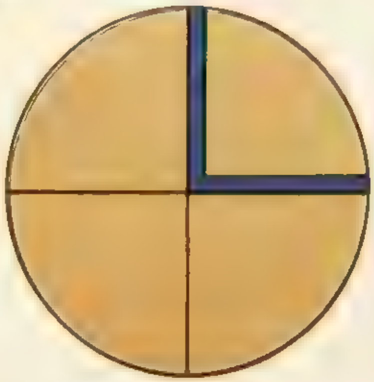
The second harmonic is an ellipsoid and, if taken with reservations, can be said to describe the elliptical shape of the Earth.

The third harmonic, taken with fewer reservations, describes the pear shape. The illustration shows a number of the harmonics that have been deduced by measuring orbits around the Earth. The use of satellites has allowed determination of the Earth's shape up to the 21st harmonic.

NEWTON'S PREDICTIONS—In 1672 a French expedition in Guiana observed variations in the swing of a pendulum they had taken with them. These variations are explained today as the result of a change in the acceleration of gravity due to the flattening of the Earth's poles, but the phenomena kept scientists perplexed until it was discovered that, on the basis of the mechanical laws governing the turning of the Earth, the planet must be ellipsoid in shape. This was announced in 1687 by Newton in his *Principia*.

Newton visualized a meridian section of the Earth in which two wells, one drilled from the pole and the other from the equator, met at the center of the Earth. The water would rise higher in the equatorial well than in the polar well, because of increased centrifugal force. Newton calculated that the difference amounted to 1/230th of the diameter of the Earth.

2



4

GEODETIC MEASUREMENT OF POLAR FLATTENING—Both the discovery made by the French expedition to Guiana and Newton's calculations encouraged scientists to look for a way to measure the extent of the flattening at the poles. A section of the Earth taken along a meridian would be ellipsoid, as in illustration 4a. (The measurements given are those of the equatorial and polar diameters.) A geometrical feature of the elliptical shape of the Earth's meridian is that a given angle of arc on the meridian has a different length at the pole than at the equator. This enables calculation of the extent of the ellipse.

For example, in illustration 4b the arc *AB* is 10° wide at the pole. It is mad[...] a perpendicular from the pol[...] second perpendicular from an[...] such a way as to form an an[...] the first perpendicular. These [...] intersect at a point below the [...] Earth. The distance *AB* is g[...] distance *A'B'*, also based on a [...] but with one line at the equato[...]

By working out the length [...] the meridian arc near the pol[...] equator, it was possible to arri[...] like the real extent of the flatte[...] accurate measurement obtain[...] geodetic technique is 1/297.1.

[...] dropping [...] then a [...] point in [...] 10° with [...]nes will [...] of the [...]than the [...]e of 10° [...]ection of [...] near the [...]mething [...]he most [...] such a

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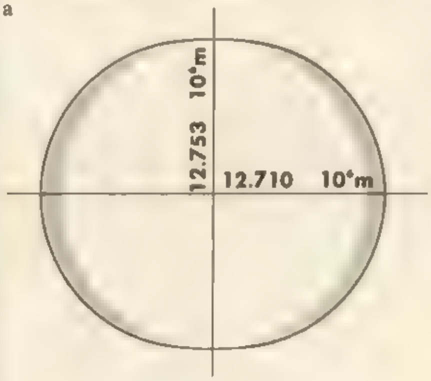

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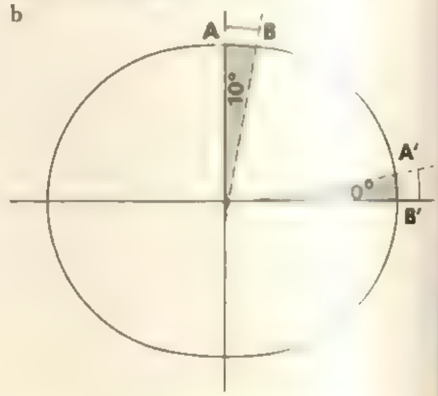

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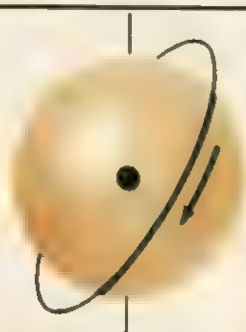

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THE AGE OF SATELLITES—In 1957 the age of space exploration by artificial satellites began. One result enabled scientists to estimate exactly how much the Earth is flattened.

If the Earth were perfectly spherical (illustration 3a), its gravitational action on a satellite would be that of a mass concentrated in a single point—the center of the Earth. A satellite traveling around a perfectly spherical Earth would never deviate from a perfectly spherical orbit. Around an ellipsoid Earth, however, if the satellite's orbit is at a steep angle to the equator, it accelerates each time it approaches the equator. As a result of this acceleration, a precession of the satellite's orbit occurs (illustration 3b). A satellite revolving at an angle to the line of the Earth's equator continues in an open orbit (illustration 3c). If the precession that has taken place after quite a number of orbits is measured, the flattening of the Earth can be calculated more accurately than through any geodetic technique. Such a measurement reveals that the flattening amounts to 1/298.25.

5

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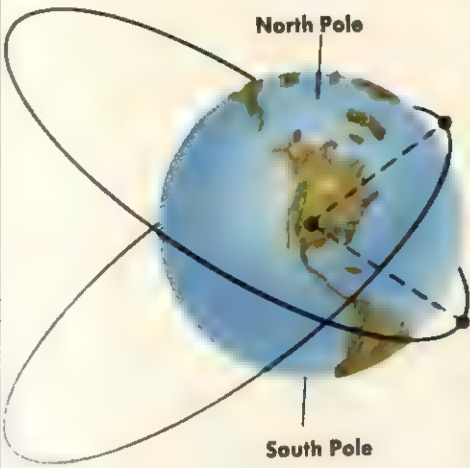

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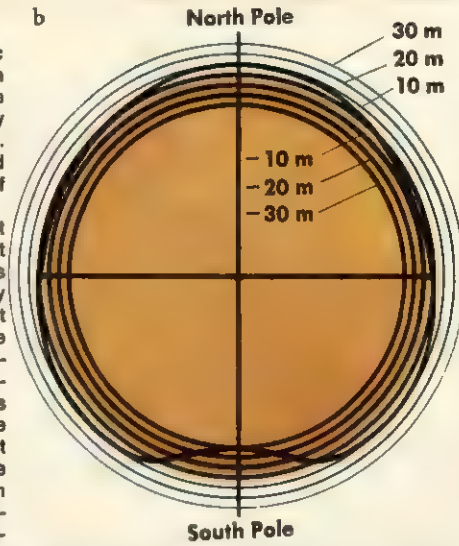
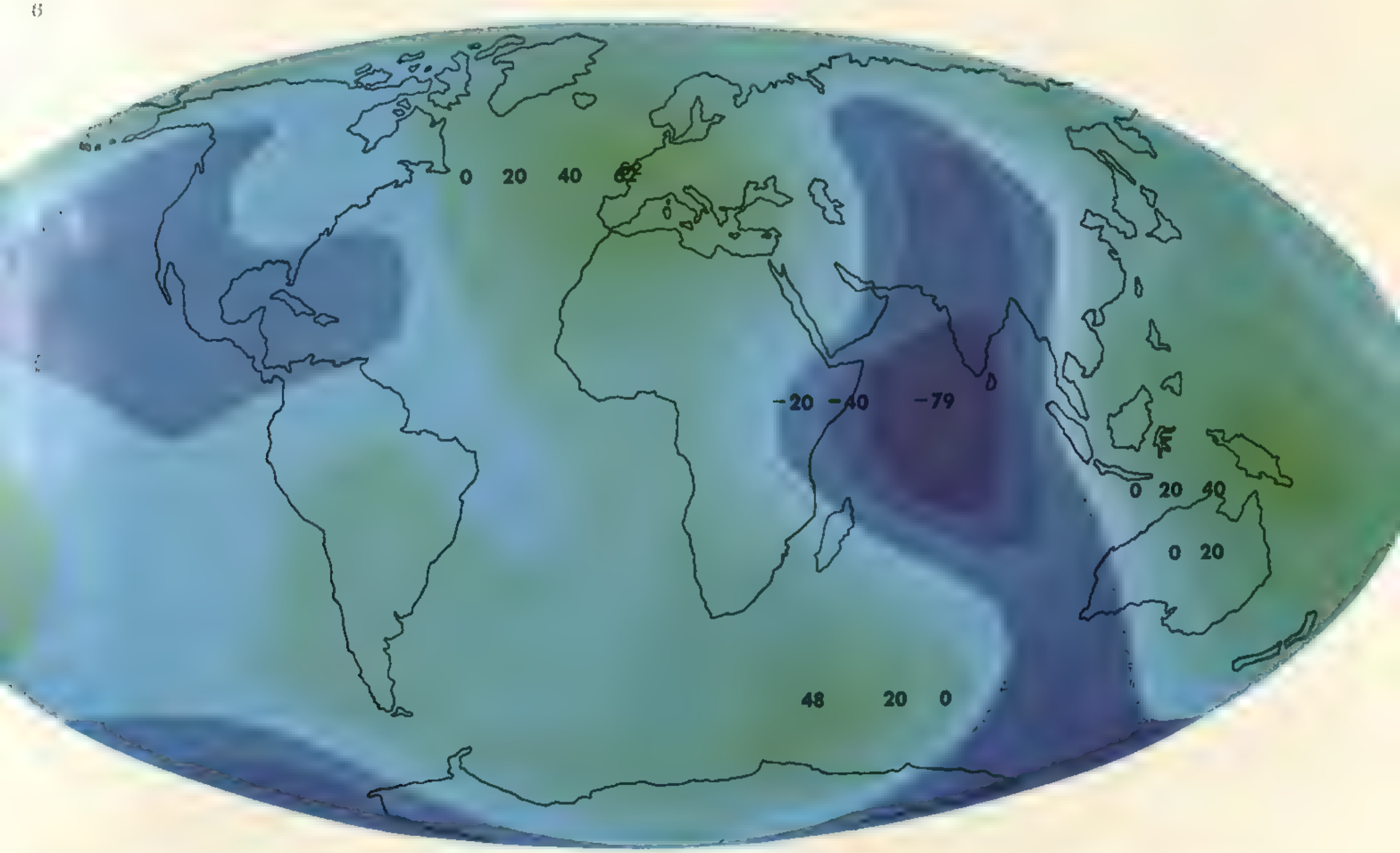


THE PEAR-SHAPED EARTH—At a time when it took courage to maintain that the Earth was a sphere, Christopher Columbus was convinced that the Earth was slightly pear-shaped although he had no scientific basis for this conviction. By means of geodetic measurements it was possible to establish that the Earth, which at first appeared to be roughly spherical, and later to be roughly ellipsoid, is in fact somewhat pear-shaped. This pear shape can be accurately calculated by observing the perigee of the orbits of satellites.

Because of perturbations, the elliptical orbit of a satellite changes not only its plane but also its perigee—the point at which it is nearest the Earth. If the Earth were perfectly ellipsoid, it would be possible to work out the exact height of the satellite above the Earth's surface by using measurements obtained with powerful cameras. Such measurements, however, have revealed that there is a change in the position of a satellite. The slight pear shape of the Earth indicates that the Earth's center of gravity is not at the center of the ellipsoid, but slightly away from it; thus, a satellite's perigee is found at different heights. Illustration 5a shows the different heights at which a satellite approaches the perigee in two different orbits. Reconstruction of the orbit of the satellite (illustration 5b) yields the pear-shaped form of a meridian section of the Earth. The circle that circumscribes the shape of the Earth is not in fact a circle but the line of reference of the ellipsoid. The pear shape of the Earth does not depart more than 30 m (about 98 ft) from the ellipsoid.

6



THE GEOID AS SEEN BY THE SATELLITES—This illustration uses the colors generally employed on maps to show relief, but in this case they indicate the shape of the geoid of the Earth—the surface that is normal to the direction of gravity and that coincides with mean sea level. The contour lines show the elevations or depressions in terms of the geoid. The maximum depression is about 80 m (about 262 ft) below the ellipsoid (a flattening of 1/298.5) in the Indian Ocean, and more than 60 m (about 197 ft) above it near the English Channel. The study of the movements of artificial satellites has enabled scientists to make an accurate map of the shape of the Earth.

FOSSIL TERRESTRIAL REPTILES

THE CYNOGNATHUS — This reptile of the Lower Triassic belonged to the most highly evolved therapsids.

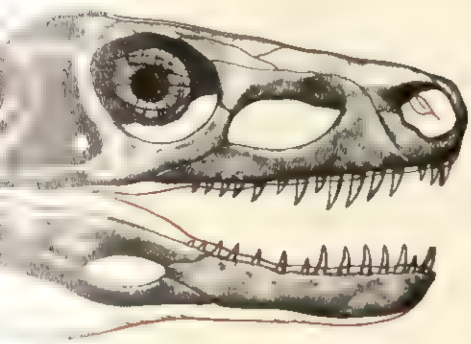
Among the most interesting of the fossil reptiles were those of the subclasses of Archosauria and Synapsida. Of the numerous orders of the Archosauria, all except that of the Crocodilia became extinct by the close of the Mesozoic era; all first appeared in the Upper Permian (of the Palaeozoic era) and produced a vast number of genera and species, including the so-called flying reptiles or pterodactyls and the well-known dinosaurs that dominated the Mesozoic continents. The first synapsids appeared somewhat earlier, at the close of the Pennsylvanian period, and by the end of the Triassic period had begun to evolve into mammals—for which reason they are known as mammal-like reptiles.

The pterodactyls or Pterosauria were the only flying reptiles that ever existed. They first appeared in the Jurassic period and some of the larger species survived until the end of the Cretaceous period. After a group life-span of about 100 million years the pterodactyls became extinct shortly before the last of the dinosaurs. The wings of the pter-

THECODONTIA—The most ancient and primitive order of the Archosauria was the thecodonts, of which many genera have been found in Lower Triassic strata. The name indicates that these reptiles had teeth fixed in alveoli or small pits in the gums, a feature shared with other groups of Archosauria and clearly demonstrating their common origin and close relationship; in fact, all the other orders of Archosauria are believed to have evolved from the thecodonts, in which are apparent certain characteristics of the later orders of Crocodilia, Pterosauria, Ornithischia, and Saurischia. (The Pterosauria are often identified through their best-known subgroup, the pterodactyls; the Ornithischia and Saurischia are popularly described as dinosaurs.)

One group of thecodonts reveals a tendency to walk on two legs, a characteristic that the dinosaurs carried to such a degree of success; another group, however, shows a four-footed structure, with such disproportion between the front and hind legs that these animals may have become quadrupeds again at a later stage. The genus *Euparkeria*, found in Lower Triassic strata in South Africa, belongs to the first of these groups. It had a fairly high and very light skull (illustration 2a), with as many as five apertures on each side and a sixth on the lower jaw, and its palate had a number of small teeth. The entire skeletal structure indicated that while the animal usually moved on four legs, it could easily have moved on two. The skeletal structure shows, in fact, a tendency toward two-footed locomotion that was not achieved completely until other genera developed in the Middle and Upper Triassic, including the *Saltoposuchus* (illustration 2b), a far more highly evolved genus that may well have been the common ancestor of the Pterosauria, the birds, and the dinosaurs. Forms demonstrating the transitions have not been confirmed, however, except for the earliest of the Saurischia, which were widespread by the end of the Triassic and the beginning of the Jurassic and were not much higher up on the evolutionary scale than the *Saltoposuchus*.

Among those thecodonts of the second group mentioned (those that tended to walk on two feet but later reverted to becoming quadrupeds) was the Aetosaurus of the Upper Triassic, with a body tending to develop considerable armor plating; this is also evident in the *Desmatosuchus* (illustration 2c) and the Phytosauria, a suborder of thecodonts that appeared and lived like crocodiles and were probably the ancestors of the order of Crocodilia.



2b

2c

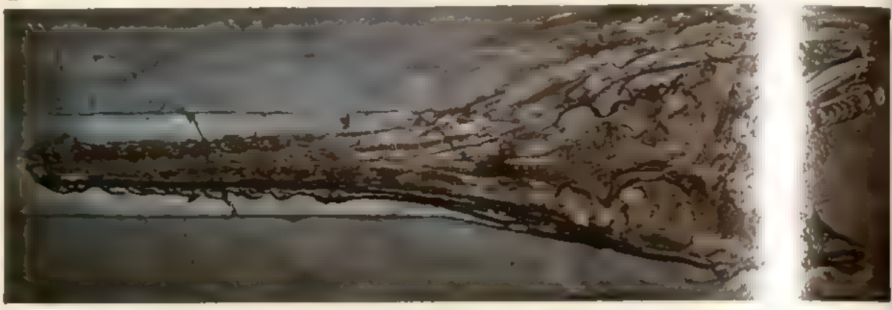
3

CROCODILES—The crocodiles, in the broad sense—that is, including alligators, gavials, and related forms—are the only living direct descendants of the Archosauria; they evolved from the thecodonts during the Triassic period.

In many respects the structure of crocodiles is not very different from that of the Archosauria, and especially from that of their ancestors, the Phytosauria. The principal change affected the palate. The chief difficulty experienced by these terrestrial reptiles that had returned to living in the water was that of opening their mouths while submerged without taking water into the windpipe. The phytosaurs solved the problem by developing nostrils on a raised knob between the eyes; but the crocodiles developed a secondary palate —as did the mammals—that allowed the nostrils to move forward. The earliest-known crocodile was the *Protosuchus*, a contemporary of the *Phytosaurus*. It had a short head, limbs similar to those of present-day crocodiles, and armor consisting of rows of bony plates that protected its back and belly. More highly developed crocodiles appeared during the Jurassic period; their secondary palates were less developed than those of existing crocodiles, but they already had the long snout of the gavials or the short snout of the alligators. Of particular interest among the Mesosuchia, a suborder of Jurassic and Lower Cretaceous periods, were a number of marine genera, including the *Mystriosaurus* (illustration 3a), which grew to a length of 13 to 15 m (about 42 to 50 ft), and the *Bernissartia* (illustration 3b).

Present-day crocodiles first appeared in the Cretaceous and reached their greatest distribution in the early epochs of the Cenozoic era.

a



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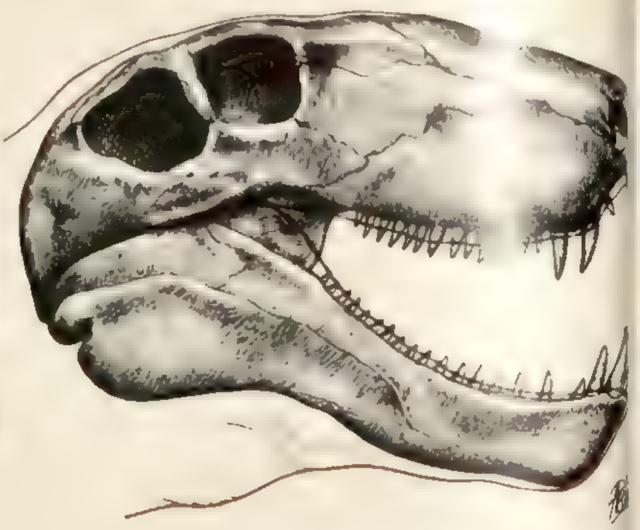


PELYCOSAURIA—At the end of the Pennsylvanian period and the beginning of the Permian, certain reptiles appeared whose principal feature was a synapsid skull—that is, one with only one pair of temporal apertures. Inasmuch as this feature was not found in any other subclass of reptiles, this new subclass was designated the Synapsida.

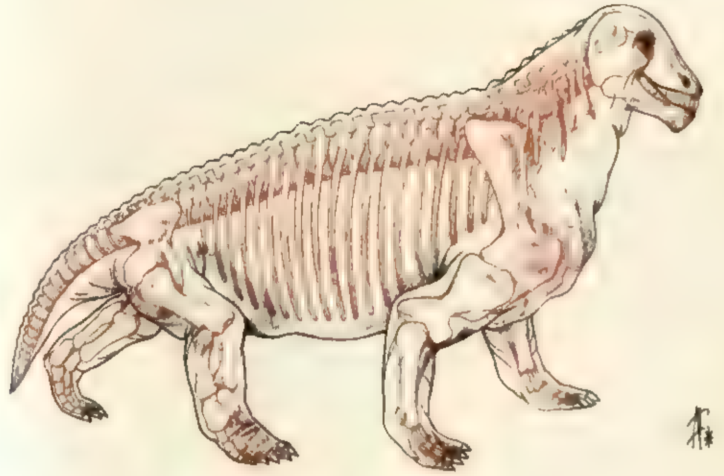
The earliest synapsid was of the order of Pelycosauria, in the Lower Pennsylvanian; it became fairly widespread throughout North America, Europe, and Africa in the Permian. A rather primitive representative genus was the *Varanosaurus*, which grew to a length of about 90 cm (about 3 ft) and looked like a large lizard. Among its numerous pointed teeth were two longer teeth near the forward edge of each jaw; these seem to have been precursors of the canine teeth so characteristic of mammals, which are actually supposed to have evolved from the synapsids.

Another and very different group of Pelycosauria may be represented by the genus *Edaphosaurus* (illustration 4a), which had quite long neural spines down its back. These must have been connected by a thick membrane. No trace of different kinds of teeth is evident.

A representative genus of another group of Pelycosauria was the *Dimetrodon* (illustration 4b), which also had fairly long neural spines as well as the mouth of a carnivore; its teeth are clearly divided into those comparable to incisors and longer, bigger teeth similar to canines.

The large dorsal membrane of the *Edaphosaurus* and the *Dimetrodon* raises the question of function. It extended 2 or 3 ft above the back in a 6-ft animal. It may have served to regulate the body heat of an animal that lived in a dry environment; exposing a larger surface to the sun, its body would become warm more quickly.

5



ERAPSIDA—A great number of the mam- ıallike reptiles that flourished between the iddle Permian and the Middle Triassic pe- riods were of the order Therapsida. They com- prised both carnivores and herbivores, and ılready had numerous features in common ith mammals.

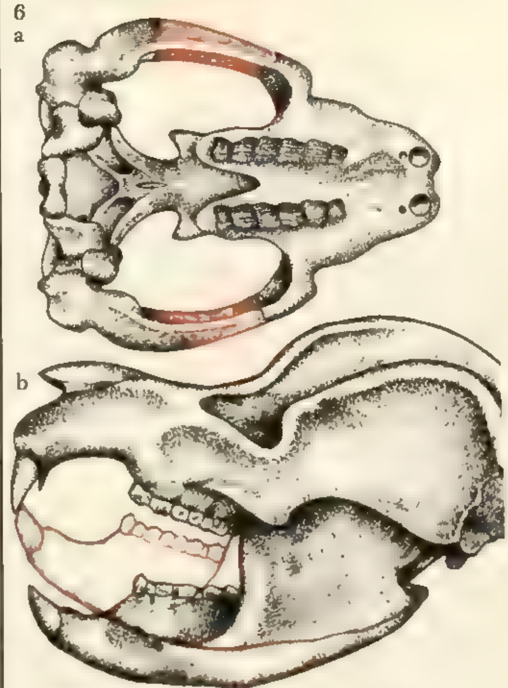
The most ancient and primitive therapsids, ating from the Middle Permian, were the ...cephalia, fossils of which have been found ...uth Africa and Russia. Their skulls re- mbled those of *Dimetrodon,* and the only ptilian features were the single occipital ondyle and the absence of a secondary palate. The teeth included a differentiated canine, and the articulated bones of the jaw, the quadrate and the articular, were quite small. (These two bones evolved, in mammals, into small ear ossicles, the incus and the stapes.) One of these Dinocephalia is the *Moschops* illustrated above.

Among the most highly evolved therapsids was the *Cynognathus* of the Lower Triassic period, shown in Illustration 1. It was a four-footed carnivore, with two occipital condyles, the same number of phalanges as a mammal, differentiated teeth (with incisors, canines, and premolars), and a secondary palate.

6

a

b



ICTIDOSAURIA — Synapsids with skeletons even more similar to those of mammals were those of the order Ictidosauria. The palate (Illustration 6a) and side view (Illustration 6b) of Bienotherium, of the genus *Tritylodon*, is shown in this illustration; it requires very close examination to establish that they belong to a reptile. As a matter of fact, merely by making observations of fossils, it is almost impossible to follow the change from reptile to mammal. Paleontology can only provide the certainty that the one class did evolve from the other—that during the Triassic period, some 170 million years ago, synapsid reptiles began to evolve into mammals.

odactyls were formed by the front limbs; he fourth finger of these was enor- ıously lengthened and supported a thin nembrane that was attached to the sides f the body and to the rear legs. The pterodactyls represented the first attempt on the part of animals to fly, an attempt that was to be perfectly realized through the evolution of another order of archosaurs into the *Archaeopteryx* (not a pterosaur) in the Jurassic Period. *Archaeopteryx* was the feathered link between reptiles and birds.

Triassic archosaurs tended toward a bipedal gait that freed the front limbs for other use. Pterosaurs converted the freed limbs into wings. In contrast with birds, and as in bats, the pterosaurs formed a wing surface by means of a membrane of skin. In bats, all the fingers except the thumb support the membrane; but in pterosaurs the membrane was attached only to the one elongated finger and extended back along the flank to the knee. An accessory membrane lay between the neck and the "arm." The first three fingers were slender and clawed. The pterosaur membrane had the disadvantage of lacking in maneuverability and of being totally affected if damaged at any point.

Pterosaurs had compact bodies. The hind legs were long and slender, and the structure suggests that pterosaurs, like bats, hung suspended by the hind limbs while at rest. The skull was light but strong. The eyes were large, and the eyeball, as in many birds, was reinforced by a series of bony plates (the sclerotic ring) lying in its walls. These reptiles also had a long slender beak. The brain was large, and apparently it was similar in pattern to that of birds. Also as in birds, sight rather than smell seems to have been the dominant sense. The typical Jurassic form of pterosaur was a small reptile, some specimens being no larger than a sparrow. Descendants of the type in the Cretaceous period were, however, much larger.

The earliest of the pterosaurs (of the suborder Rhamphorhynchia) had long tails, sometimes ending in a kind of small rudder. More highly evolved were those suborders of pterodactyls that had no tails. These animals reached extraordinary sizes, such as that of the *Pteranodon* of the Cretaceous, with a wingspan of 6 m (almost 20 ft). This genus had long beaks very suitable for fishing, and a long, flat appendix to the skull, pointed backward, that might have been used as a counterweight to the beak or as a rudder to adjust direction during flight. It is interesting to note that all flying reptiles had long claws on their front and back feet, for clinging to rocks or trees. It seems unlikely that they could hop along the ground as birds do, and they are thought to have lived on high sea cliffs, swooping down to catch fish and then returning to their nests without landing elsewhere.

The value and chief interest of the Archosauria, however, is that they evolved into birds. In all probability, such evolution came about through some ancestor that was common to both the pterosaurs and the dinosaurs.

CONTINENTAL BLOCKS IN AGES PAST | jigsaw puzzle on a grand scale

Until a few years ago the theory of continental drift was accepted merely as an attractive but unproved hypothesis that helped to explain certain observations made by geologists and paleontologists. In the past few years, however, a great deal of study has been devoted to the problem of continental drift, and the importance of this study to an understanding of the geological and paleontological history of the Earth has become increasingly apparent.

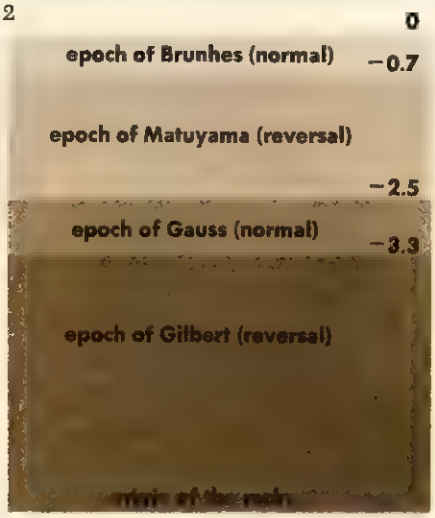
Maps have been prepared to show the continents as they existed during different geologic periods; all these maps differ greatly from present-day maps of the Earth. However, a comparison of the ... reveals areas (such as North America and portions of northern Europe) that more or less correspond in outline to the continents of today. Substantial reasons exist for believing that these two continents were joined at some time in the ... Similarly, evidence indicates that South America and South Africa were also connected; in the past, scientists have suggested that these two landmasses in the Southern Hemisphere were once linked by a kind of long, narrow land bridge, but this suggestion receives little support today.

The studies that have done most to confirm the theory of continental drift have been those concerned with paleomagnetism, a science that is finding increasing applications as the handmaiden of geology. On the basis of numerous studies and reconstructions, scientists have made maps showing the magnetic field of the Earth as it existed during each era of the past and during certain periods as well. With current knowledge of the history of the Earth's magnetic field, scientists reconstruct geological phenomena of the remote past. One of the most significant applications of paleomagnetic study is in the confirmation of the theory of continental drift.

...PUTER IN SERVICE OF A THEORY—The ...tal configurations of the continental blocks ... suggested that perhaps the continents ...re once joined together. This observation ...s one of several observations leading to the ...ation of the continental-drift hypothesis. ...al examination of a map reveals how cer... features of the eastern coastline of the ...mericas seem to coincide or dovetail with ...rtain features of the western coasts of ...urope and Africa. However, such an examination provides a very inexact notion of how these blocks may have fitted together in the distant past. The map shown here, however, indicates the juxtaposition of the continental masses, including their continental shelves, as they have been defined by precise geometric study. In other words, the map shows the present outlines of the continents, surrounded by those areas presently under water to a depth of 900 m (about 2,900 ft).

It is possible for a scientist to trace on cardboard the outlines of the continents with their continental shelves, cut out the pieces, and discover the proper juxtaposition of the pieces by trial-and-error manipulation—much as one would fit together the pieces of a jigsaw puzzle. However, the arrangement depicted on this map was accomplished through the use of a computer, which enabled scientists to calculate precisely those areas in which the continental shelves overlap (shown in black) and those in which the shelves are separated (shown in white). The slight variations in the outlines of the continental masses may well have occurred since that remote time when the masses were joined together.

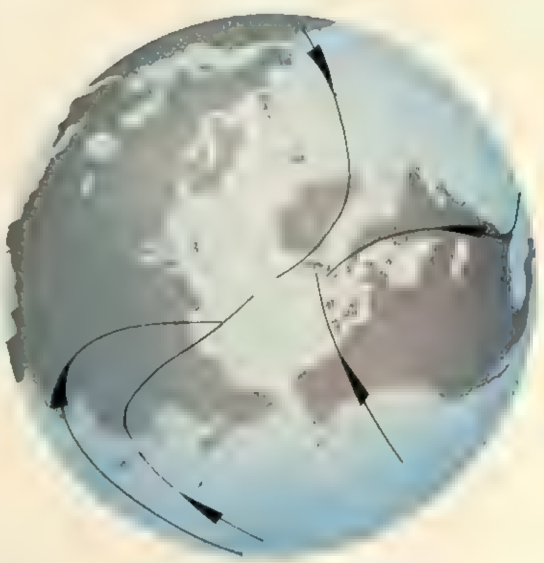
2

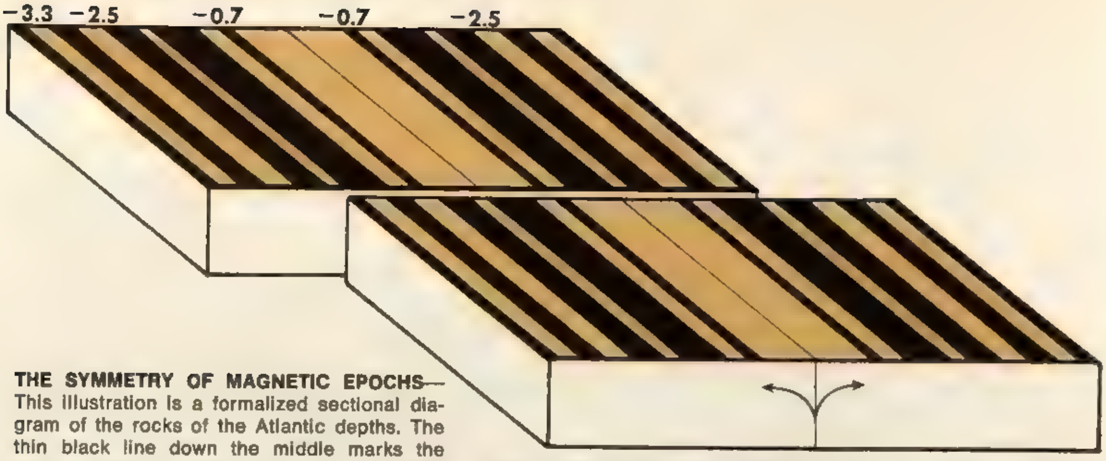


EPOCHS OF MAGNETIC POLARITY—Stratigraphic diagrams are used to represent many phenomena of sedimentation and paleobiology. A typical stratigraphic diagram consists of a vertical column divided into sections that correspond to the proportional depths of various rock strata or to the periods when certain species of animals existed. The diagram shown here represents, in an approximate way, the polarity of the Earth's magnetic field. It is known that in the past the magnetic field has been reversed or inverted, so that what is now the north magnetic pole became the south magnetic pole and vice versa. The epochs of magnetic polarity have been named after eminent students of magnetism. The polarity as it exists today—considered here as the normal situation—has spanned the last 700,000 years. The period prior to that, extending back about 2.5 million years, was primarily a time of reversal. Before this period a time of normal polarity occurred after an epoch of reversal.

3

THE MIGRATION OF THE MAGNETIC POLES—In the course of geologic time the magnetic poles of the Earth have undergone apparently extraordinary changes of position. These shifts or migrations have constituted, if not voyages around the world, at least trips to the other side of the Earth. Today it is thought that these apparent shifts resulted from movements of the continents in relation to the poles, rather than from actual changes in the positions of the poles. The arrows on this map show how the magnetic north pole appears to have wandered during geologic time. However, if it is assumed that the continents of South America, Africa, and Australia were connected or grouped closely together during the late Paleozoic era, the lines representing the paths of polar wandering would more or less come together.





THE SYMMETRY OF MAGNETIC EPOCHS— This illustration is a formalized sectional diagram of the rocks of the Atlantic depths. The thin black line down the middle marks the zone in which the range of oceanic mountains rises in the Atlantic. The yellow and black areas on both sides of this axis signify, by their colors, the alternating normal and reverse polarities of the Earth's magnetic field. It is clear that the story of the magnetic field is the same on one side of the axis as it is on the opposite side. This can be explained only by supposing that magma rose along the line of the axis and that this material spread out on both sides of the axis at exactly the same speed. In this way a perfect symmetry of magnetic polarities may have occurred.

The displacement of the two blocks represents a fracture zone. On both sides of the line of the main fracture an identical series of rocks is found, but the position of the entire series has been shifted or displaced. The map in Illustration 4 shows the locations of fractures in the rocks of the ocean bed.

The reconstruction of the history of magnetic polarities in the oceanic mountain ranges is the product of endless a ture of ocean beds. To m tion it was first necessa detail the topography of t ticularly the main systems Then, samples were tak floor to discover the locat finally, new samples had permit the calculation of ities of the past. For obvio were taken from a great n

ls of the struc- is reconstruc- map in great ean floor, par- ges and faults. m the ocean the fractures; e obtained to agnetic polar- sons, samples r of points.

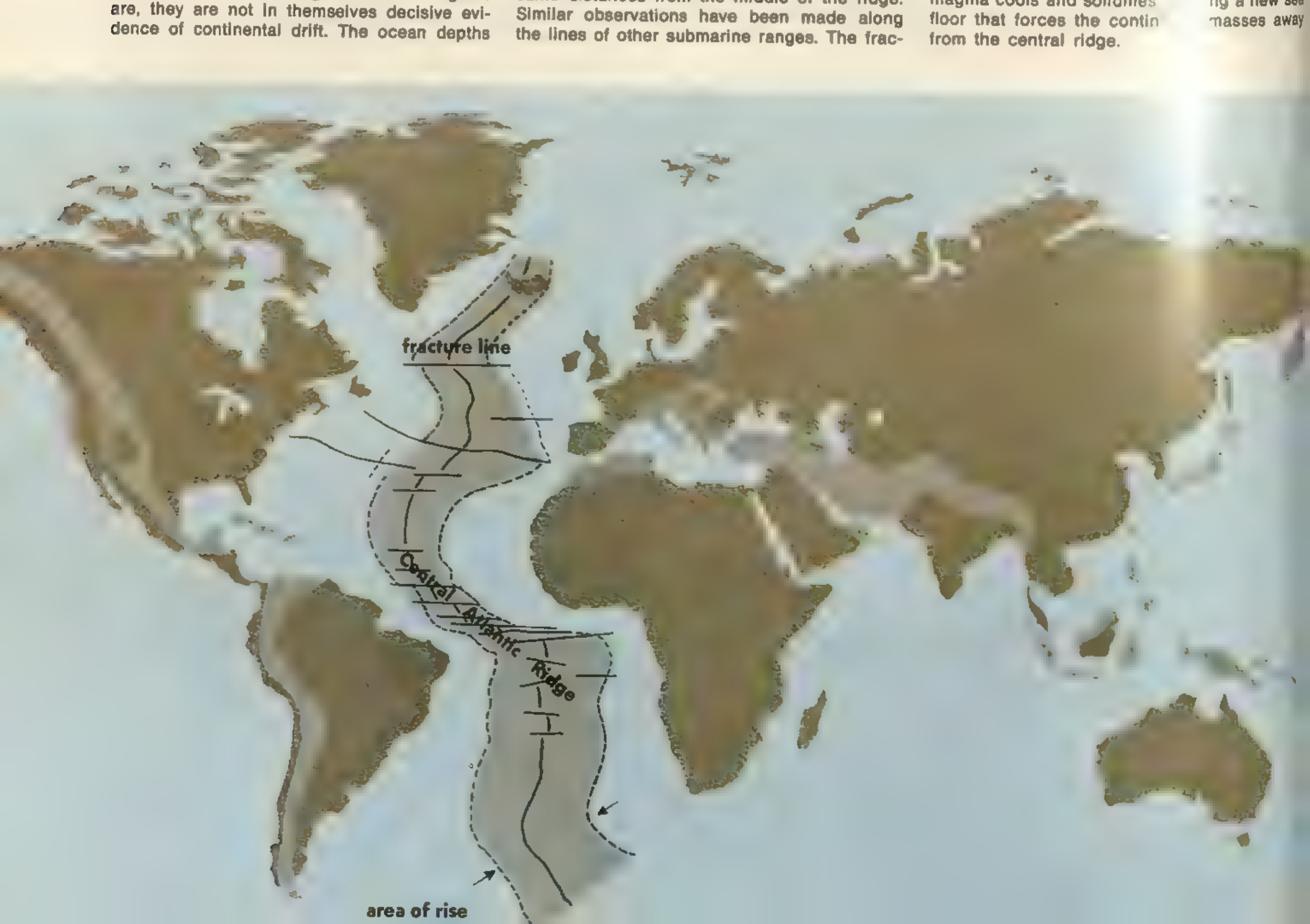
THE GEOLOGY OF CONTINENTAL DRIFT— This map depicts the continents with their present shapes and in their present positions. All the major landmasses are represented by the same dark color; areas of unusually high mountains are indicated by a lighter color. These heavily wrinkled regions, which are associated with very intense volcanic activity, are also areas in which the greatest number of deep and intermediate earthquakes are recorded

Interesting as the high mountain regions are, they are not in themselves decisive evidence of continental drift. The ocean depths provide more significant evidence of this geologic phenomenon. For example, fairly recent studies have revealed the existence of vast submarine mountain ranges, such as the great ridge extending down the middle of the Atlantic Ocean from the Arctic to the Antarctic.

Today it is possible to study the paleomagnetism of the rocks on either side of this colossal underwater mountain range. Identical magnetic phenomena have been discovered on both sides of the ridge, at approximately the same distances from the middle of the ridge. Similar observations have been made along the lines of other submarine ranges. The fracture zones are indicated broken lines indicate oute

The crust of the Earth tinents is relatively thick, km (about 20 mi); by c areas, the rocks of the Ea cated very near the surfa with a thin layer of crusta extreme pressure and hig low, molten rock or mag places to form oceanic mo magma cools and solidifies floor that forces the contin from the central ridge.

ack lines; the of the rises. ying the con- ging about 32 t. In oceanic nantle are lo- are covered s. Due to the peratures be- ses in these ranges. The ng a new sea masses away



THE CRETACEOUS PERIOD | the end of an era

The Cretaceous period lasted for about 60 to 65 million years, from approxi-nately 130 million years ago until about 5 or 70 million years ago. It lasted early as long as the two periods follow-g it, the Tertiary and the Quaternary. he Earth, as in all other periods, was relatively rapid process of evolution; ious geologic phenomena (such as genesis, transgressions, and regres-s) succeeded one another and left ost complete records of the changes the rocks of the period. A detailed opsis of all the changes of geologic rest would require an enormous unt of space. Therefore, the geologic tory of the Cretaceous is covered here broad outline form only.

he name of this period is derived a Latin word meaning *chalk,* and it rs to a characteristic rock deposited ing late Cretaceous times over large ions of northwestern Europe. Where exposed along the English Channel, forms the familiar white cliffs of Dover. alk, however, was not the predominant type of rock formed during this period. Thick deposits of sandstone, shale, coal, and conglomerate were accumulated on the land, and mudstone, limestone, and some thick beds of material of volcanic origin were formed in the seas—in addition to the chalk. The vertical sequence of these rocks is usually divided into two portions, the Lower and the Upper Cretaceous sequences.

In order to compare the relative ages of rock sequences the world over, a standard of named stages, representing succeeding time intervals, was established for the European sequence, beginning with the Neocomian, the oldest. Age correlation of Cretaceous beds in different parts of the world is based, in the case of marine sediments, largely on widely distributed species of ammonites, which are among the more reliable guide or index fossils of the period. Other useful fossils in certain marine deposits are the echinoids. In identifying and correlating the beds of the continental deposits, plant assemblages and dinosaurs have been used.

Many rocks of Cretaceous age have economic importance in the present day, being used for building stones, ceramic products, cement, and glass sand. The most important products, however, are oil, natural gas, coal, and water. Oil-bearing rocks are widespread in the Americas and northern Africa. Thick coal deposits are found in North America, Germany, Japan, and New Zealand; coal from these deposits is principally of bituminous and lignitic quality. Porous Cretaceous rocks are important sources of artesian water.

BDIVISIONS OF THE CRETACEOUS SYSEM—This system of subdividing the Cretaous rocks is based on the study of European rmations. Eight subdivisions are shown in is diagram, but some writers put the number gher, and others put it lower. Sequences of etaceous rocks in other parts of the world re subdivided differently.

UPPER CRETACEOUS	Danian
	Maestrichtian
	Senonian
	Turonian
	Cenomanian
LOWER CRETACEOUS	Albian
	Aptian
	Neocomian

GENERAL GEOGRAPHIC CHARACTERISTICS OF THE CRETACEOUS

In early geologic studies, Europe received the most attention. During the Cretaceous period, this region was covered by two rather different kinds of seas—in the south by a sea that was destined to become the Mediterranean, and in the north (what is now Central Europe) by a shallow epicontinental sea, rich in sediment and fossil characteristics. Slight changes in the depth of this sea occurred frequently during the Cretaceous, resulting in the deposition of a great variety of animal and lithological types. Today, therefore, detailed stratigraphic study permits a fine subdivision of the period into relatively short epochs and ages. As yet it is impossible to establish the exact beginning and ending dates of these epochs and ages.

On the eastern borders of the European plain, where Europe now ends and Asia begins, lay the so-called basin of the Russian Sea, which at first was just a gulf opening out of the Arctic. Later on it extended farther and joined up with the Tethys Sea, which since earlier times (except for short interludes) had formed a link between the sea occupying the site of the present Mediterranean and the seas of the Far East. The latter then covered what is now the southern part of Central Asia.

Biologic, geologic, and paleomagnetic studies suggest that the Continent of Gondwanaland was breaking apart during the Cretaceous period. North and South America probably appeared much as they do today, except for the Caribbean land mass which occupied the site of the present archipelago.

THE CLIMATE

It is likely that the Earth experienced a diversity of climates during the Cretaceous period. Many parts of the planet must have been hot during the Cretaceous, but this is not known with absolute certainty. However, the presence of breadfruit and fig trees indicates that subtropical climates existed. The widespread distribution of angiosperms also indicates the existence of temperate climates. In addition, evidence of glaciation and aridity has been discovered. Dense vegetation, which produced coal deposits, indicates considerable rainfall.

OROGENESIS AND IGNEOUS ACTIVITY

The orogenic phenomena of the Cretaceous were impressive, although they did

THE CRETACEOUS WORLD—The map of the Earth during the Cretaceous period differs somewhat, but not greatly, from a map of the modern world. Scientists know that shallow seas covered some areas that are now dry land, but they are uncertain as to how much water lay between the continents. Presumably North and South America were still joined to Europe and Africa, and Gondwanaland was essentially a single block. Many of the world's great mountain ranges were taking shape or, at least, the orogenic movements that would uplift them were in process.

The map shows the Cretaceous world as it existed in the Senonian epoch.

From time to time the Russian Sea changed in size, while the White Chalk Sea (so-called because of its characteristic chalk deposits) underwent a whole series of transgressions and regressions, which complicate the study of the resulting deposits. The transgressions and regressions alternated with such frequency that great domes of evaporated salts were formed, and subsequently these domes were transformed. Many areas, generally in the vicinity of the geosynclinal seas, underwent intense magmatic or igneous activity.

not leave any particular imprint. The Sakawa Mountains arose in Japan, and, although not a very large range, they bear testimony to a powerful movement in that region of Asia. Horizontal thrusts, producing slides with covering folds, occurred both in the Rocky Mountains and in the region where the Alps now extend between Austria and Bavaria.

The huge masses of serpentine that today appear as outcrops in the Ligurian Apennines are the remains of the igneous eruptions of the Cretaceous period. This magmatic activity was caused by the same kind of movement that would later bend and uplift the Alpine region.

In India, great magmatic eruptions formed the basaltic lava flows of the Deccan region.

BIOLOGICAL PHENOMENA

The Plant Kingdom offers perhaps the most exciting novelty of the Cretaceous period: the appearance of angiosperms or flowering plants. At the same time the many kinds of cycadeoids, conifers, and ferns began to decline.

Changes also occurred in the Animal Kingdom. The lower animals diversified into an enormous number of species; certain very important forms of higher organisms made their appearance; and, perhaps of greatest significance, some groups of animals became extinct, after having dominated various realms of the Earth.

Fossiliferous rocks of Early Cretaceous times are almost exclusively marine in nature, and early continental fauna are confined to a few formations, chiefly in southern England, northern France, and Belgium. However, great areas of continental sediments of Late Cretaceous age exist, notably in the western parts of the United States and Canada and in the central and eastern parts of Asia. The marine faunas of the Cretaceous continued for the most part the pattern that was

racteristic of the Jurassic period, but ious groups underwent gradual modnization.

The foraminifers were still well repreted, and the ammonoids were still tiful, although the latter were desd for complete extinction by the end he period. Several orders of coelentes appeared for the first time. Cuttleand belemnoids were fairly common, ls were plentiful, and some nautiontinued to survive. Moreover, the octopods made their appearance. Peods (bivalve mollusks) and gastro- (snails) abounded in the Cretaseas, as they had in the waters of ssic times. Bryozoans were also very merous. The most common brachioagain as in the Jurassic, were the ratulids and rhynchonellids. Echiwere even more numerous and did than in the preceding period, rinoids were rather plentiful.

ong the fish, the radial development rks continued, so that by the end period all common modern types represented. Most groups of skates rays had also appeared before the nd of the Cretaceous. Among the bony h, the teleosts developed very rapidly.

Aquatic reptiles continued to be plentiul. The plesiosaurs were in existence, th the short-necked variety prevalent. he Ichthyosaurs declined, and they may have become extinct long before the end of the Cretaceous. Lizards took to the water during this period, and the chalk deposits of Late Cretaceous age are replete with fossils of mosasaurs. Crocodiles and turtles were numerous, and specialization was evident among the latter.

Lizards became plentiful for the first time during the Late Cretaceous, and the snakes (of lizard ancestry) made their appearance. Flying reptiles, exemplified by *Pteranodon*, reached their peak in both size and flying ability.

As in the previous periods of the Mesozoic, the dinosaurs continued their domination of the terrestrial environs. Among the common and most interesting species were the ornithischians (bird-hipped dinosaurs), *Iguanodon*, and the duck-billed *Trachodon*, a number of types of small, intermediate, and large carnivores, and the armored ankylosaurs and ceratopsians (horned dinosaurs), including the giant *Triceratops*. Perhaps the most fearsome of the carnivorous dinosaurs was the colossal *Tyrannosaurus*.

Birds of the Cretaceous were still quite primitive. Late in the period, certain oceanic birds made their appearance; notable among them were *Hesperornis*, a toothed, flightless, diving bird, and *Ichthyornis*, a bird with a modern, highly developed type of wing.

Mammals were still rare. Survivors of archaic orders were present in the early part of the period; however, the first representatives of the modern marsupials (pouched mammals) and eutherians (placental mammals) appeared during the latter part of the Cretaceous.

ANIMAL LIFE AT THE END OF THE ERA

With the conclusion of the Cretaceous period, the great span of geologic time known as the Mesozoic era came to an end, and many organisms that had long been prominent ceased to exist. During the Mesozoic, life had developed enormously, at times evolving giant forms, and had spread to every conceivable habitat on land and in the sea. The rocks of the Cretaceous period contain a remarkably rich record of this fauna.

In one sense the fauna of the Mesozoic era suggests a planet on which a balance had been established—a planet on which the species retained their own well-defined characteristics while living in harmony with one another. The dinosaurs dominated the Mesozoic realm; indeed, the most highly evolved organisms were reptiles. These animals experimented with various forms of attack and defense; some of them were covered with great bony plates, and a few (the turtles) were protected by thick exoskeletal armor containing not a single chink. Adaptations in bodily structure were almost endless: some reptiles adapted themselves for attacking their prey and their enemies by acquiring more weight and muscular strength; others adapted to the need for flight from their enemies by acquiring lightness; while still others adapted to aquatic conditions by taking on special forms for ease of movement in water.

The Mesozoic era lasted about 155 to 160 million years. One might assume that life had achieved a state of equilibrium in which no further changes would occur—that the best forms of life had already been evolved and that further evolution might well be limited to details of form and adaptation. Such was not the case, however, for the entire situation was suddenly and catastrophically upset at the end of the Cretaceous period. Within a relatively brief span of time, the picture of an apparently stable ecology was utterly changed. The ammonites, for example, issued signs of crisis in their evolution during the final part of the Cretaceous, because they tended to regress to more primitive forms. Paleontologists feel justified in saying that, when a living form begins to regress along the path of evolution, that form is about to become extinct—and the ammonites did become extinct. But what may be said of the dinosaurs, which continued to show a remarkable flair for adaptation, continually changing their forms and habits until they became extinct? Only relatively small representatives of the reptilian class have survived to the present day.

Mention must be made of the organisms destined to open the new season of animal life. The mammals continued their slow evolution, tending to remain in the background, while the birds took on new and more highly evolved forms. The reptiles moved toward forms that would survive into modern times, such as the forms of certain types of aquatic and terrestrial turtles. The snakes made their appearance, while the crocodilians developed in a number of forms that have since remained unchanged.

Even lower forms of life underwent great changes, and their forms became sufficiently distinct to provide a picture of the associations of the Cretaceous.

THE LANDSCAPE OF THE CRETACEOUS PERIOD | scene of the dinosaurs' last nd

Paleontologists, the scientists who try to reconstruct the forms of prehistoric organisms and to trace the evolution of life, find their task eased when working with fossils from the Cretaceous and more recent periods. Fossils dating from the Cretaceous and subsequent periods are numerous, and they represent species closely resembled by species existing today.

In all probability, the beginning student of the Cretaceous would be most impressed by the great number of enormous reptiles, especially dinosaurs, that occupied the Earth during this period. He might also be impressed by the paucity of species–namely the mammals and the birds–that characterize the present age. Nevertheless, the Cretaceous produced many lower organisms, such as the clamlike members of the class Lamellibranchia (pelecypods), which possessed habits and forms quite close to those of their modern relatives.

The resemblance between the Cretaceous period and the present day extends also to vegetation. During previous periods, huge forests of conifers–not totally unlike modern coniferous forests–existed. But in the Cretaceous, especially in the Upper Cretaceous, forests even more similar to modern forests were plentiful. These ancient forests consisted of a number of highly important species of broad-leaved trees similar to those still in existence.

At the beginning of the Cretaceous, true flowering plants were a minor element, at least in the fossil record. It has been suggested, however, that the flowering plants might have already inhabited the highlands, where the chances of their preservation as fossils would have been extremely limited; and it may be that angiosperms expanded their range into the lowlands, increasing their chances for preservation in the rapidly accumulating sediments.

THE SEA DURING THE CRETACEOUS PERIOD—Countless biological changes occurred in the sea during the Cretaceous period. Noteworthy among the changes were the appearance of giant teleosts (bony fish), the expansion of larger forms of mollusks, and the evolution of echinoderms and sponges.

There were fewer coral reefs in the Cretaceous than in previous periods. This paucity of coral reefs is a positive indication that the Cretaceous climate was colder than that of preceding periods, because relatively high temperatures are required for the corals to survive. In addition, many of the seas of most importance in the study of organic evolution were exceptionally shallow, and perhaps even muddy—conditions antagonistic to coral life. Corals were not completely absent from Cretaceous seas, of course, but they were less widely distributed than in the Triassic and Jurassic.

The name of the Cretaceous period is derived from the Latin word meaning *chalk*, and was first applied in connection with the chalky formations bounding the English Channel. Chalk formations, which consist of very fine-grained calcareous soil rich in the remains of foraminifers, are also common in Europe and North Africa. The most important foraminifers of the Cretaceous seas were the *Globotruncana* and the *Orbitolina*.

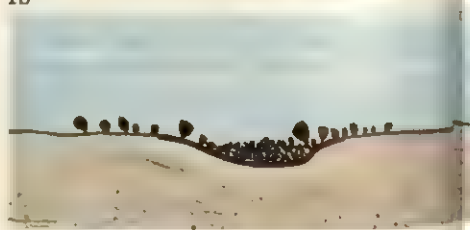
The generally light-colored chalk deposits contain occasional nodules of flint, which were formed wholly or partly from the remains of radiolarians. These nodules may also contain silica from siliceous sponges common in Cretaceous seas.

Illustration 1b shows the process that led to the formation of the flint nodules. Actually, two processes were at work at the same time: sedimentation and segregation. The siliceous parts were pushed together into sacs which became the flinty nodules. These are found today between the softer Cretaceous chalks; the chalk may be split to reveal the flint. In regions affected by erosion the flint may be found as a protruding mass on an eroded plain.

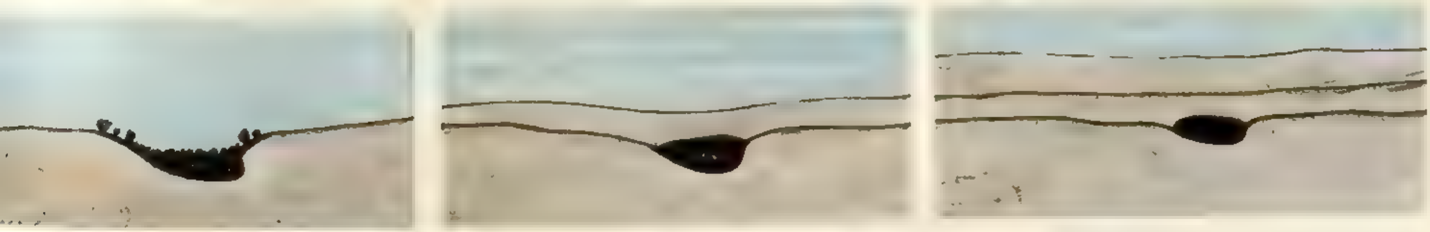
Illustration 1a shows some of the important organisms associated with the sea in the Cretaceous times. Many calcareous sponges **a** lived on the sea floor in shallow waters. *Micraster*, *Toxaster*, *Stenoia*, and other echinoids or sea urchins predominated at the expense of other kinds of echinoderms, especially the crinoids or sea lilies **b.** Brachiopods, gastropods, and cephalopods were also abundant on the sea floor. Some species of brachiopods, mollusks, and higher forms were destined to survive, while others were fated to disappear. For example, the once-dominant ammonites and the great aquatic reptiles, *Plesiosaurus* and *Ichthyosaurus*, were destined to become extinct by the end of the

1a

1b



Cretaceous. Among the organisms destined to survive were the fish, an exemplar of which was *Portheus molossus* **c.** Great marine turtles, such as *Archelon* **d,** were quite numerous in Cretaceous times, and their descendants



have occupied the seas ever since.

Besides these large creatures, many smaller kinds of animals, especially fish, must have lived in the Cretaceous seas. Otherwise, it would be impossible to explain how the sea became a hunting ground for a vast number of animals, including aquatic reptiles, such as *Plesiosaurus* **e**, and flying reptiles, such as *Pteranodon* **f**, shown soaring over the sea in search of food. Fossils of these huge flying reptiles often have been found with remains of fish in their stomachs. A large number of the reptilian species adapted to life in the water also ate mollusks.

THE LANDSCAPE—Reptiles dominated the landscape during the Cretaceous period, just as they had during most of the two preceding periods. This illustration shows a few of the most highly evolved dinosaurs that ever lived on Earth at the same time. *Trachodon* **a** was an aquatic, duck-billed, bird-hipped herbivore, while *Tyrannosaurus* **b** was the largest, most ferocious carnivore ever to appear on the face of the Earth. The huge horned dinosaur *Triceratops* **c**, despite its size and fierce appearance, fed solely on plants. Another herbivore, *Iguanodon* **d**, was one of the first giant reptiles to be restored by paleontologists. All the dinosaurs shown in the illustration were common in the Cretaceous environment, and the presence of many animals of enormous size presupposes the existence of an abundance of plants and a multitude of smaller animals, both of which served to satisfy the appetites of these monsters.

Snakes crawled along the ground and among the reeds of the Cretaceous landscape; in marshy places, many species of turtles thrived, along with numerous crocodilians whose forms were similar to those of present-day varieties. The colossal *Pteranodon* **e** soared through the Cretaceous atmosphere, often in company with smaller species of flying reptiles. At the same times, primitive birds were evolving forms that would eventually give them control of the air.

At ground level, the mammals had begun to entrench themselves. Cretaceous mammals appeared rather like larg[illegible]nts **f** and became the rulers of the [illegible] underbrush. Some of the mammals were [illegible]ctivores, while others were carnivores. Fe[illegible]sects existed in the Cretaceous than in [illegible] periods, but their numbers increased [illegible]usly in subsequent periods.

Although forests of con[illegible]re still present during the Cretaceous[illegible]lars, willows, bay trees, oaks, plane tr[illegible]nd birches—all quite similar to modern [illegible]cies—thrived in the Cretaceous landsc[illegible] Undoubtedly, the single most important [illegible]ical development of the period was [illegible]pearance of flowering plants. Parts of th[illegible]e were such familiar trees as oak, map[illegible]lnut, poplar, and magnolia as well as shr[illegible]d grasses.

2

FLORA OF THE CRETACEOUS PERIOD | appearance of the flowering plants

← **A MODERN ANATOMICAL CONSTITUTION**—Scientists have determined the histological anatomy of the trilobites of the Paleozoic Era by studying specimens that had been buried and fossilized in very fine sediments. Many plants from the Cretaceous period also became fossilized in such sediments. Even though these fossil remains do not enable scientists to examine details (such as the stomata), they do permit observation of the entire network of veins in the leaves. This photograph shows a well-preserved specimen of *Otozamites klipsteinii*, one of the Bennettitales or cycadeoids.

In the history of life on Earth, plants have evolved much more slowly than animals. Plants living today are the products of an evolutionary process that began a very long time ago. Therefore, it is not too surprising to discover that the flora of the Cretaceous period was quite similar to modern flora, while the fauna of the Cretaceous was still rather primitive compared with present-day fauna.

The floristic highlight of the Cretaceous was the sudden appearance and widespread distribution of the angiosperms or flowering plants; on the other hand, the most representative animals belonged to groups that had made their appearance in previous periods. The birds, while retaining certain primitive features such as teeth, closely approximated present forms; the mammals, still close to their primitive ancestors, included the earliest marsupials and eutherians (placental animals).

In its physiological organization, a plant is much more primitive than an animal, but it is capable of providing those qualities of resistance required for survival under adverse conditions. In their early stages of ev[illegible]tion, animals followed the forms that [illegible] proved successful in the vegetabl[illegible]orld: unicellular structures copied [illegible]acteria, and later on Porifera (spo[illegible]) and corals appeared with forms th[illegible]peared more vegetable than anim[illegible]xamples of close resemblance be[illegible] plant and animal forms exist all [illegible]way up the biological ladder until [illegible]echinoderms and crinoids are reach[illegible]

If an observer coul[illegible] transported back in time so that [illegible] could walk through a Cretaceous [illegible], he would certainly see, between [illegible]ees, a number of animals that [illegible] since disappeared, animals that [illegible]r only the vaguest resemblance to a[illegible]als of today. On the other hand, he [illegible]ld find the forest itself to be more [illegible]ess familiar.

THE CRETACEOUS FOREST—No single illus-tion can provide a complete synopsis of Cretaceous forest, because in the course the 60 to 65 million years of the Cretaceous iod, the forest underwent a long and no-e evolution, from the time when gymno-rms were prevalent to the time when angio-ms were dominant. An effort has been le to represent this evolution, nevertheless, depicting the more ancient forms in the hand part of the illustration and the more ent ones on the right.

pecially in the Early Cretaceous, many grew on the forest floor. These were not elike ferns that characterized the Penn-ian period, although many large spe-did exist. Treelike ferns were present, but were not so common as in the Carbon-us period.

e Bennettitales, including the *Cycadeoi-a*, reached their highest point of develop-nt. Most of the flora of the Lower and Mid-Cretaceous belonged to the group of nnettitales; but, with the coming of the Upper Cretaceous, these plants went into a swift decline, while the angiosperms came into their own as the dominant plants.

The Cretaceous forest also contained an abundance of conifers, including *Araucaria* **b**, *Abietinea* **c**, and *Sequoia* **d**.

Little can be said about a forest without considering the climate. Data concerning climate, if they come from different places, very often disagree. Climate depends on many factors, including the geographic position of a region (its latitude, elevation, and proximity to large bodies of water) and meteorological phenomena such as winds. It is impossible to understand the variations and peculiarities of climate if the geophysical characteristics that determine climate are unknown.

The Cretaceous climate, at least in certain regions, underwent a gradual change that undoubtedly had a considerable influence on the evolution of the flora. The climate must have been more or less tropical when the flora shown in the left-hand part of the illustration existed. This can be deduced from the forms of the plants and from the thickness of the annual growth rings. Conifers, which are mostly evergreen trees, lend themselves to the analysis of growth rings; any variation in the thickness of the annular rings must be due entirely to climatic factors.

At a certain point, a fairly sudden change occurred in the landscape of the Upper Cretaceous; the climate changed from tropical to subtropical, producing greater differences between the seasons. Once again, this has been deduced from a study of the annual growth rings of the trees. The change in climate was favorable to the development of the angiosperms, which are quite adaptable to climate variations.

In the Cretaceous forest at this point appeared some of the trees that are most familiar today: the poplar, willow, and laurel (which thrive in a damp climate); the birch **e**, oak **f**, the plane tree **g**, and *Taxodium disticum* **h**, which prosper in a moderate climate; and the eucalyptus, which can survive in an almost arid climate.

THE MOMENT OF TRANSITION—A few species of angiosperms existed during the Triassic period, but the flowering plants increased enormously during the Cretaceous. The Cretaceous, therefore, can be considered the period of transition from gymnosperms to angiosperms. In fact, gymnosperms flourished during the first part of this period, but their numbers decreased drastically during the latter half of the period. Nevertheless, large forests of *Cycadeoidea* and Abietineae were still extant, and *Sequoia* were also present. All in all, Upper Cretaceous flora differed little from present-day flora. This photograph shows a cone of *Araucarites* found in Cretaceous deposits. The cone was solidly constructed, but scarcely different from the cones of many species flourishing today. The layer of brittle rock covering the fossilized part gives the cone an almost new appearance; it is difficult to believe that this cone fell from a tree about 100 million years ago.

Among the larger plants he would observe many species belonging to families known today, families whose members still contribute to the beauty of the landscape.

DEVELOPMENT OF THE ANGIOSPERM

The speed with which different kinds of animals appeared and disappeared often makes it difficult to determine with accuracy the length of time they endured on Earth. In the Plant Kingdom, on the other hand, the very slowness of the evolutionary process makes it difficult to fix the date of the appearance of a species. Nevertheless, as already indicated, the angiosperms or flowering plants developed greatly during the Cretaceous period. A few angiosperms existed in the Triassic; but what may be termed an evolutionary explosion occurred during the Cretaceous.

The dominant plants of the Earth's vegetation, the angiosperms consist of about 325 to 350 families, 12,500 genera, and somewhat more than 250,000 species. They preserve watersheds, and they are essential to the maintenance of a balance in all of nature through their role in the nitrogen and carbon cycles. The angiosperms occupy every land area of the Earth. They are abundant in rivers and freshwater lakes, and some ... n grow in shallow waters of the ocean ... thers persist in tropical desert areas ... h less than an inch of rainfall every f... ears. The angiosperms are among th... st of trees (the *Eucalyptus*) and the ... st of rain forest lianas (the rattan pa... *Calamus*), and the smallest of floweri... iants, with bodies a fraction of an in... cross (the duckweed, *Wolffia*). An... erms also embrace every aquatic ... terrestrial herb.

A PROBABLE CONNE... N

The Carboniferous was ... ed by an enormous expansion of th... lant Kingdom. It cannot be said ... certainty that this expansion during ... Carboniferous caused the popula... explosion of terrestrial animals duri... the Mesozoic era, although large n... ers of animals could not have exist... vithout an adequate food supply. B... same token, it cannot be said tha... spread of the angiosperms caused—... indirectly—the great development o... mammals during the Tertiary period ... hat is certain, however, is that the ... acts are in some way connected: ang... rms resist climatic changes better th... ther kinds of plants, while of all the ... als, mammals seem best adapted to ... e kinds of alterations in the environm...

PORTRAIT OF DECLINE—This photograph shows a very fine example of *Sewardia latifolia*, another plant that declined in importance at the end of the Cretaceous period—until it almost vanished altogether. This specimen is superbly preserved in a deposit of extraordinary fineness.

THE DINOSAURS | members of the order Saurischia

1

THE SAUROPODS—The Sauropoda, which lived until the end of the Lower Jurassic and survived for about 20 million years, evolved from the Theropoda. They look completely different from their cousins, the Theropoda. Their forelegs, although shorter than their hind legs (clearly indicating their bipedal origin) were nevertheless strong enough to allow a four-legged stance. Their enormous lengths of up to 25 m (about 80 ft) might suggest that the sauropods were carnivorous; however, the Sauropoda, the largest terrestrial animals that ever lived, actually were herbivores. Even the largest sauropod had a feeble set of teeth situated in a small skull supported by a neck so long that the animal was able to gather the underwater plants on which it fed incessantly. Its enormous weight, estimated at nearly 50 tons, would have made it very difficult for the animal to move around on dry land; therefore, scientists believe that this huge creature habitually lived almost submerged in marshes or lakes.

Among the best known genera of sauropods whose skeletons have been found are *Brontosaurus*, over 25 m (about 80 ft) long, and *Diplodocus*, of a similar length but a lighter build (Illustration 1).

One day in the spring of 1822, Dr. Gideon Mantell, an English physician and an enthusiastic collector of fossils, went to visit a patient in the country nearby. His wife went with him, and while waiting she found some teeth in the rock of a recent road cut. She showed the teeth to her husband, who then examined the road cut himself and discovered more teeth and some bones. The physician thought the fossils were so strange and interesting that he decided to send them to the great anatomist, Baron Georges Cuvier, in Paris. Cuvier assigned the bones to a species of extinct hippopotamus and the fossil teeth to a species of extinct rhinoceros. Dr. Mantell was by no means satisfied with Cuvier's decision. Some time later, another scientist pointed out to Mantell the remarkable similarity between the large fossil teeth and the very much smaller teeth of the iguana. Mantell therefore gave the name *Iguanodon* (iguana-tooth) to the animal from which the teeth came. Dr. Mantell's intuition was correct, for years after the discovery of the *Iguanodon* teeth, a number of complete specimens, clearly showing their reptilian nature, were removed from Cretaceous rocks in Belgium.

In 1824, two years after Mantell's discovery, the English paleontologist Dean William Buckland described some remains unearthed near Oxford—remains that belonged to a large animal that he named *Megalosaurus*. Unlike *Iguanodon*, it showed clear signs of having been carnivorous.

In 1855, some teeth and vertebrae were discovered in Montana, and these remains belonged to an animal somewhat similar to *Iguanodon;* it was named *Hadrosaurus*. These early findings led scientists to believe in the existence of a large group of extinct carnivorous and herbivorous reptiles. Continuous research has brought to light a vast number of specimens of these a[...]ls, constituting a group within the [...] Reptilia. The English paleontologis[...] Richard Owen called the extinct a[...] *dinosaurs*, a name derived from th[...]ek, and meaning *terrible lizards* [...]rtunately, perhaps, the name do[...] indicate any precise position in a [...] of taxonomic classification and t[...]re has lost much of its scientifi[...]rtance; nevertheless, it is still in [...]t use among scientists and laymen [...].

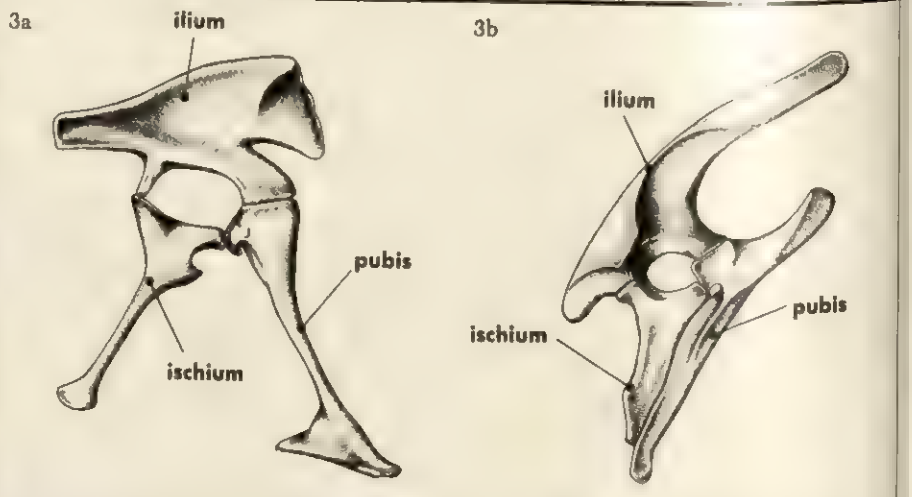
The dinosaurs co[...]ed two separate orders of repti[...]he Saurischia and the Ornithischia. [...]lifferences between the two order[...]e of the same degree as the differen[...]tween lizards and snakes. Neverth[...] members of the two orders had [...]al forms that were similar in many [...]ects.

The dinosaurs wer[...] reigning reptiles during the Meso[...]era; because of their predominanc[...] Mesozoic is often called the "Age [...]e Dinosaurs" or the "Era of the R[...]s." Dinosaurs first appeared on the [...]h during the Triassic period, which [...]n about 225 million years ago, whil[...] last of them disappeared about 65 [...] million years ago, after having bee[...]e undisputed masters of the dry land [...]vell over 100 million years.

Taxonomically, dinos[...] are included in the subclass Archos[...], which also includes the crocodil[...] the theco-

2

MANTELL'S DISCOVERY—This illustration depicts several of the fossil teeth discovered in 1822 by Dr. Mantell. Realizing that they were similar to the teeth of an iguana, he gave the name *Iguanodon* to the animal to which they had belonged.



THE PELVIC STRUCTURES OF DINOSAURS—An important difference between the two orders of dinosaurs lies in the structure of the pelvic or hip girdle. In the Saurischia **a**, the pubis extends forward; in the Ornithischia **b**, the pubis extends backward and runs parallel to the ischium. On the basis of their pelvic structures, saurischians frequently are called lizard-hipped dinosaurs, while ornithischians are known as bird-hipped dinosaurs.

donts, and the pterosaurs or flying reptiles, every member of this subclass has a skull with two temporal apertures (fossae) separated by the squamosal and postorbital bones.

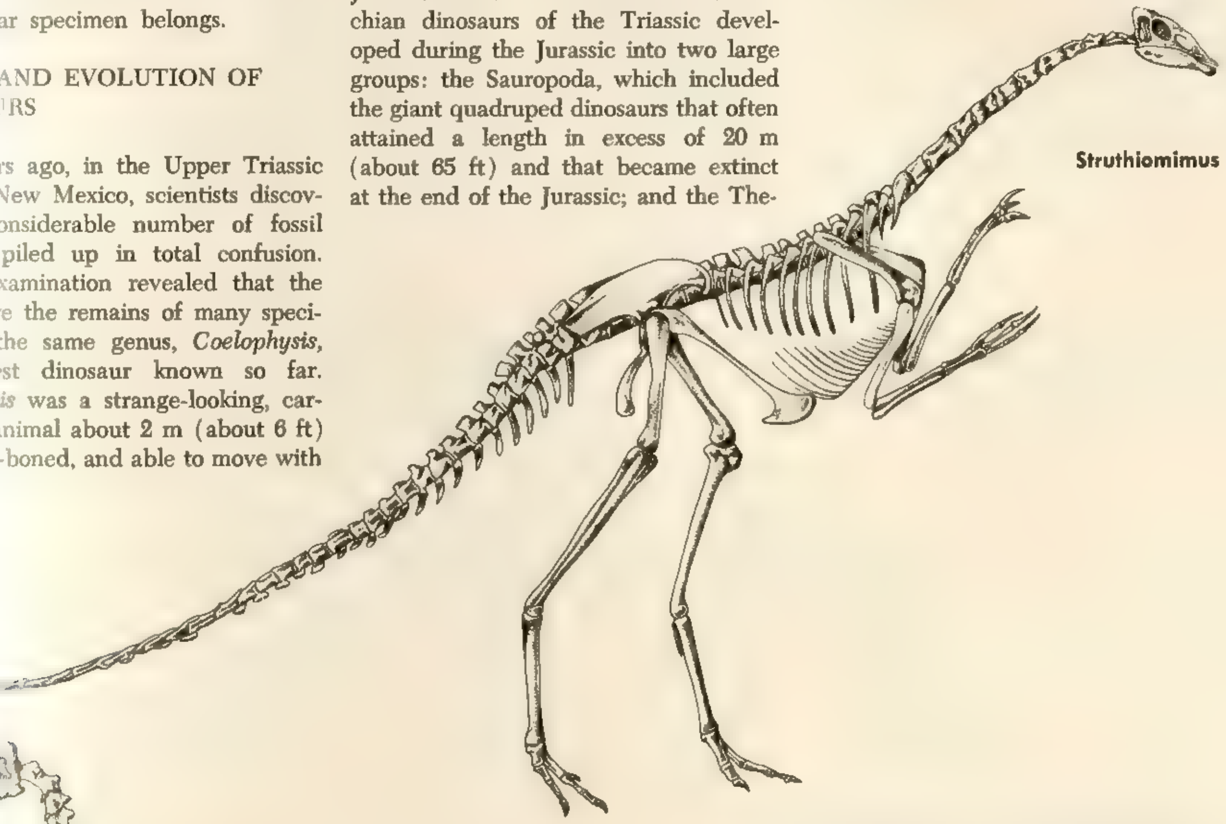
A substantial difference exists in the pelvic bones of the two orders of dinosaurs. A mere glance at the pelvic or hip girdle of a dinosaur enables a paleontologist to determine the order to which a particular specimen belongs.

ORIGIN AND EVOLUTION OF DINOSAURS

Some years ago, in the Upper Triassic strata of New Mexico, scientists discovered a considerable number of fossil skeletons piled up in total confusion. Careful examination revealed that the bones were the remains of many specimens of the same genus, *Coelophysis*, the earliest dinosaur known so far. *Coelophysis* was a strange-looking, carnivorous animal about 2 m (about 6 ft) long, light-boned, and able to move with great speed on powerful hind legs. Its forelimbs, armed with claws, were much smaller than the hind limbs, while its long tail must have been used in maintaining balance while running.

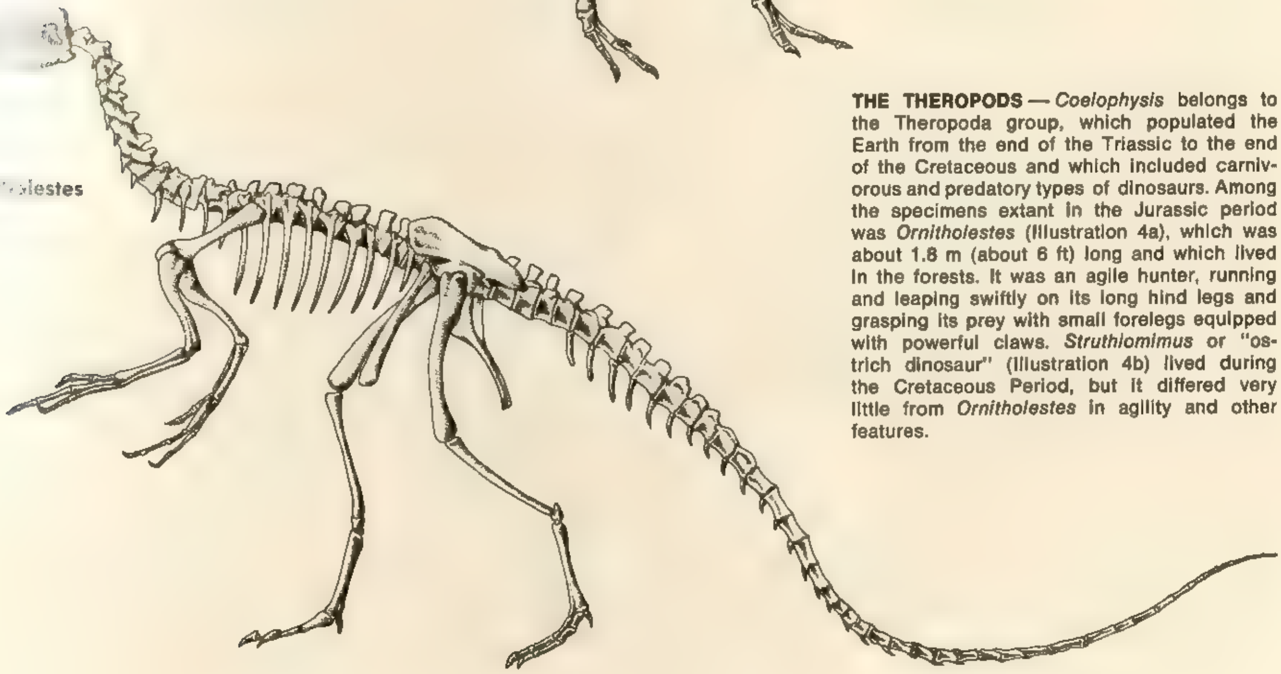
The history of the Saurischia, then, began with *Coelophysis*. The first specimens of the Ornithischia are more recent, appearing some time during the Jurassic. The undifferentiated saurischian dinosaurs of the Triassic developed during the Jurassic into two large groups: the Sauropoda, which included the giant quadruped dinosaurs that often attained a length in excess of 20 m (about 65 ft) and that became extinct at the end of the Jurassic; and the Theropoda, which included the only carnivorous dinosaurs that ever existed and which survived until the end of the Cretaceous. The order Ornithischia is divided into the Ornithopoda of the Jurassic and Cretaceous periods, the Ceratopsia and Ankylosauria of the Cretaceous, and the Stegosauria of the Jurassic only.

4b



Struthiomimus

4a



Ornitholestes

THE THEROPODS — *Coelophysis* belongs to the Theropoda group, which populated the Earth from the end of the Triassic to the end of the Cretaceous and which included carnivorous and predatory types of dinosaurs. Among the specimens extant in the Jurassic period was *Ornitholestes* (Illustration 4a), which was about 1.8 m (about 6 ft) long and which lived in the forests. It was an agile hunter, running and leaping swiftly on its long hind legs and grasping its prey with small forelegs equipped with powerful claws. *Struthiomimus* or "ostrich dinosaur" (Illustration 4b) lived during the Cretaceous Period, but it differed very little from *Ornitholestes* in agility and other features.

THE ORNITHISCHIA | the bird-hipped dinosaurs

THE CAMPTOSAURUS—Smaller than *Iguanodon, Camptosaurus* grew to a length of about 7 m (about 23 ft). An herbivorous dinosaur of the Upper Jurassic period, it lived chiefly in what is now the United States. The Ankylosauria, which evolved from the suborder Ornithopoda during the Cretaceous, were impressive armored dinosaurs. The best-known genera are *Ankylosaurus* and *Nodosaurus* of the Upper Cretaceous; these dinosaurs were as heavily armored as tanks and, next to the turtles, were the best-protected of all animals. In appearance they must ... borne remote resemblance to the arma... of today. *Ankylosaurus* had a thick, l... ng body supported by four legs, with ... orelimbs much shorter than the hind li... The teeth were very small or nonexistent

The second order of dinosaurs, the Ornithischia (bird-hipped dinosaurs), is much younger than the Saurischia (dinosaurs with lizardlike hipbones), for the earliest specimens appear in rocks of the Middle Jurassic period. Nevertheless, scientists think that the bird-hipped dinosaurs probably had a more ancient origin and evolved either from the Saurischia themselves or from some common ancestor.

The order Ornithischia is subdivided into four suborders: Ornithopoda, Stegosauria, Ankylosauria, and Ceratopsia. The most important is Ornithopoda, because this suborder contains many different species and because it gave rise to the other suborders. The ornithopods, living from the Middle Jurassic through the Upper Cretaceous, had a longer evolutionary history than the other ornithischians. In Jurassic and even Cretaceous times, certain ornithopods remained relatively small in size; but, as in other groups, there was a trend toward gigantism. The *Iguanodon* reached about 15 ft in height.

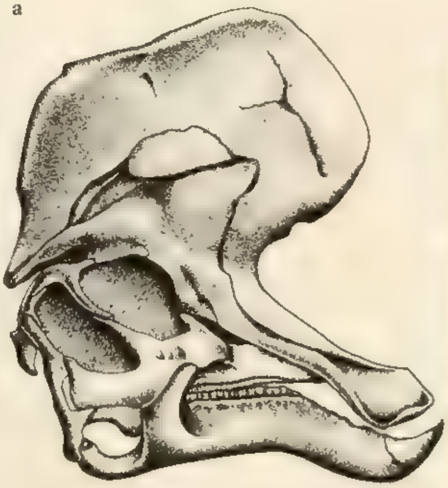
Among the four-footed ornithischians, which abounded in the Late Cretaceous period, were the horned dinosaurs, such as *Triceratops*. These had remarkable head development, including three large bony horns on the skull—two above the eyes and one above the nose.

Students of life in the past have long been concerned with the problem of the dinosaurs' extinction at the end of the Cretaceous. Although the problem has held great fascination for laymen and scientists alike, it has never been resolved to the complete satisfaction of everyone. At one time, people believed that some general catastrophe at the end of the Cretaceous period put a sudden end to the long life history of the dinosaurs. This hypothesis is no longer valid, for paleontological findings increasingly tend to exclude such a possibility. Besides, if such a catastrophe had occurred other forms of life would have been extinguished along with the dinosaurs; and it is well known that many of these other forms of life (including certain kinds of reptiles) survived into later periods.

If a catastrophe di... ...ur, it must have taken place in th... ...logical sense of the word; that is, a ... movement that led to the format... ...new mountain ranges and, theref... to a general change in the appeara... of the continental masses. This in t... would have led to changes in climat... which would have had repercussions on the animal and plant life of the time. Climatic changes, therefore, were probably instrumental in the extinction of the dinosaurs, because these animals were more likely to be affected by the climate than were the less specialized animals. The giant herbivores, because of their vast bulk, must have grazed incessantly in order to satisfy their need for food. Obviously, even the slightest change in vegetation due to climatic changes could have been fatal to such highly specialized animals, which must have been unable to adapt to the new ecological conditions. Once the herbivores had disappeared, the carnivores that preyed on them also became extinct because their source of food was gone. The large carnivores ap-

[illegible] -CK-BILLED DINOSAURS—The sub- or[illegible] -rnithopoda also included a number o[illegible] -eous dinosaurs that, because of the pe[illegible] formation of their skulls, are known as [illegible]-billed dinosaurs. They were large, bip[illegible] animals well suited to marsh life. Their [illegible] were useful for rooting around in the mu[illegible] find the vegetable food that they ne[illegible] n vast quantities. Among the best- [illegible] -era was *Anatosaurus*, of which two m[illegible] d specimens have survived, com- ple[illegible] skins. These animals had webbed fe[illegible] modern ducks, and they were adapted to [illegible] or less the same kind of environment as [illegible]. While the outward shapes of these an[illegible] -ere similar from species to species, th[illegible] varied considerably. Illustration 2a [illegible] -kull of *Lambeosaurus*, while Illus- [illegible] shows the skull of *Corythosaurus*

a



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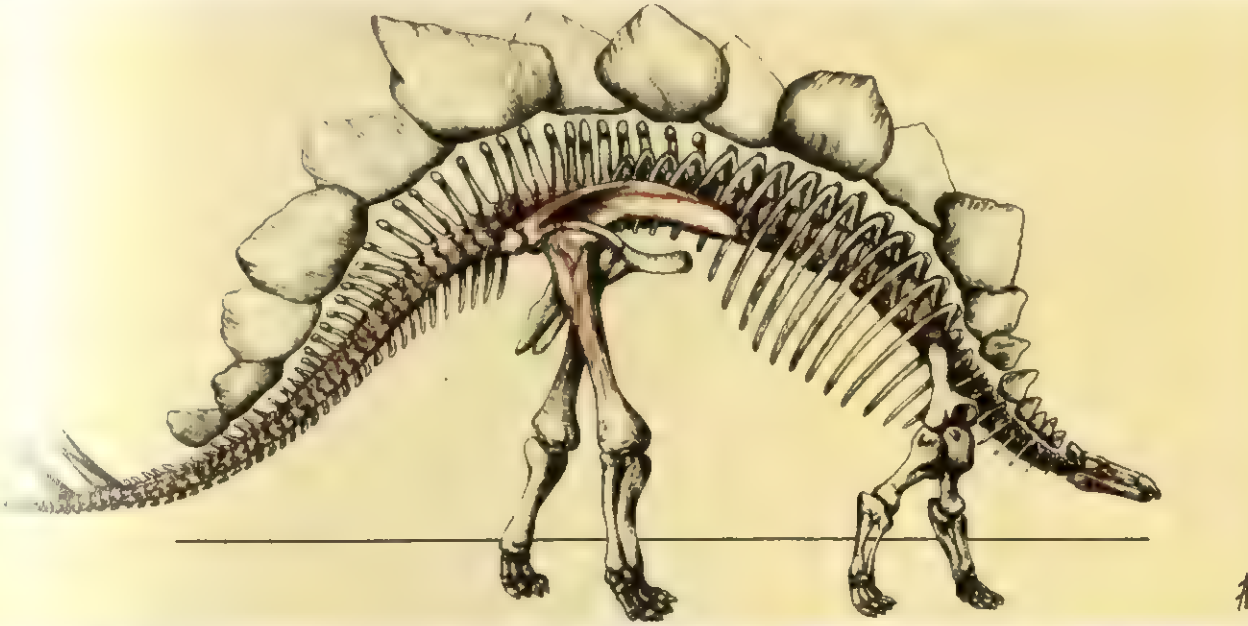


THE STEGOSAURUS—The Stegosauria evolved from the Ornithopoda during the Middle Jurassic and became extinct at the end of this period. Few fossil specimens exist. *Stegosaurus* itself is the best-known member of the Ornithopoda. The animal whose reconstructed skeleton is shown here lived in North America about 140 million years ago. Its rounded body was over 6 m (about 20 ft) long. *Stegosaurus* walked on all fours, but the fact that its forelegs were much shorter than its hind legs indicates that the animal descended from bipedal forms.

Stegosaurus had a double row of bony plates down the middle of its back, but their function is unknown. Four long, tough spikes projected from its tail, which the animal must have used as a defensive weapon. However, the most bizarre feature of this dinosaur was the swelling in the spinal marrow near the pelvis. This swelling was larger in diameter than the brain itself, which was contained in a minute skull. The swelling may have functioned as a secondary nerve center to transmit nervous impulses to the hind part of the body. This supposition gave rise to the saying that the *Stegosaurus* reasoned *a posteriori*.

parently were unable to prey successfully on the mammals, which were then much smaller than now and much more nimble than the dinosaurs.

The development of the mammals during the Cretaceous may have been another factor in the extinction of the dinosaurs, for the mammals must have preyed on the nests of the reptiles, eating the eggs and drastically reducing the dinosaur birth rate. The conclusion of all this theorizing is that the dinosaurs had reached a stage of racial senescence; that is, they had acquired such a degree of specialization that no further changes could take place that might have enabled them to adapt themselves to the new living conditions.

Therefore, not one factor but many factors led to the extinction of dinosaurs some 65 to 70 million years ago.

THE CENOZOIC ERA | early epochs of the Tertiary period

At the end of the Cretaceous period, the curtain fell on a world dominated by huge reptiles; when it raised again, the stage was occupied by plants and animals similar to those of today. The huge saurians had disappeared, but angiosperms (flowering plants) were abundant. The forests resembled present-day forests both in location and in the kinds of plants comprising them. The mammals, which had been small, relatively unimpressive animals during the latter parts of the Mesozoic, proliferated and diversified at a rapid rate; in a relatively short span of time, they became the dominant animals on the Earth.

The entirety of geologic time from the end of the Mesozoic to the present day has been designated the Cenozoic era. The term *Cenozoic* has been derived from an amalgamation of Greek words meaning "recent life." It was during this era that some of the Earth's most important mountain ranges were formed, including the Alps, the Apennines, the Rockies, the Atlas chain, the Himalayas, and the Pyrenees. When they first arose, these ranges were somewhat different from what they are now. They covered the same areas, of course, but they were much less rugged in appearance than at present. Glaciation and other forms of erosion have given these mountains their present shapes.

SUBDIVISIONS OF THE CENOZOIC ERA

The Cenozoic era ordinarily is divided into two periods, the Tertiary, which began about 65 to 70 million years ago, and the Quaternary, which began a little over two million years ago. These period names actually are carry-overs from an older system of dividing geologic time; what are now known as the Paleozoic and Mesozoic eras were once called the Primary and Secondary eras, respectively.

The Tertiary period is divided into five epochs: the Paleocene, the Eocene, the Oligocene, the Miocene, and the Pliocene. The Paleocene epoch extended from about 65 to 70 million years ago until about 55 million years ago; the Eocene, from about 55 million years to about 38 million years ago; the Oligocene, from about 38 million years ago to about 27 million years ago; the Miocene, from about 27 million years ago to about ten million years ago; and the Pliocene, from about ten million years ago to just over two million years ago.

The last two million years or so constitute the Quaternary, which is the latest and by far the shortest geological period. In a sense the Quaternary is just a small fragment of the Tertiary that has been given special attention because many significant evolutionary events have taken place during the past two million years. Probably the most outstanding event was the appearance and development of men.

The Tertiary period is clearly distinguished from previous periods by well-known biological phenomena such as the disappearance of the dinosaurs and the ammonites, as well as by its absolutely clear stratigraphical subdivisions. Tertiary formations are easily distinguishable from Cretaceous formations. In Italy, for example, Cretaceous formations are characterized by marine facies and fine deposits; Tertiary rocks, on the other hand, are typified generally by marine facies of little thickness or even by continental facies.

BIOLOGICAL HAPPENINGS

To provide an outline of all the biological events of the Tertiary would be a difficult task. However, several events of great significance must be mentioned. The first primates, lemurlike animals, made their appearance; these animals were equipped with grasping "hands" or, at least, prehensile organs. In addition, the ancestors of several important families of animals were present in the early epochs of the Tertiary, including the ancestors of the modern horse.

Mammals became adapted to life in the sea, and later became distributed throughout all climatic zones and in all possible habitats. For the whole of the Miocene epoch (about 17 million years) the mammals were the masters of the world. They included huge rhinoceroses and mastodons; the latter were the ancestors of the hairy or woolly mammoths of the Quaternary period, which were hunted by early men. Specimens of the great elephantine mammoths have been preserved in ice in Siberia and Alaska. The Tertiary also witnessed the appearance and development of many animals closely related to modern giraffes, antelopes, cattle, cats, marsupials, and other kinds of mammals. Finally, the evolution of the birds proceeded rapidly.

THE PALEOCENE AND EOCENE EPOCHS

At one point in the early studies of the Tertiary period, geologists decided to call the first half of the period the Eocene epoch, in order to denote the dawn (*eo-*) of recent (*-cene*) life. Subsequently, as more and more was learned about this segment of Cenozoic history, the Eocene was subdivided into three separate epochs; the very earliest epoch was named the Paleocene, the second epoch retained the original name, Eocene, and the third epoch was christened the Oligocene.

The flora of the Paleocene and Eocene epochs differed slightly from present-day flora, principally because the climates of the various regions of the Earth were not the same as they are today. The differentiation in the Plant Kingdom was due to the process of extension and retraction.

Paleocene and Eocene fauna also differed somewhat from the modern fauna. At the end of the Cretaceous period, a great many species of pelecypods (bivalves) and other mollusks became extinct. The marine fauna indeed exhibited a sufficient number of differences from the fauna of the preceding period to enable scientists to distinguish clearly between the Mesozoic and the Cenozoic.

On dry land, the most conspicuous event was the rapid development of mammals. This development is of interest for several reasons, among them the fact that mammalian evolution can be traced in great detail. Some mammals appeared during the Paleocene and Eocene, evolved, and disappeared before the end of the Tertiary; others appeared but became extinct during the Quaternary (that is, within the past two million years or so); still others appeared, evolved, and have survived to the present day.

THE FOSSIL BIRDS | feathered animals in prehistoric times

A RECONSTRUCTION OF ARCHAEOPTERYX—The earliest bird known is *Archaeopteryx lithographica* (Illustration 1), a poor flier about the size of a crow. Its features clearly show its phyletic derivation from the reptiles.

In the course of geologic time, many kinds of animals have attempted to conquer the atmosphere. Some have had conspicuous success, while others, including present-day flying fish, lizards, and flying squirrels, have acquired the ability to glide briefly through the air, but cannot be classified as fliers.

The first animals to adapt themselves perfectly to flight were the insects. As early as the Carboniferous (about 300 million years ago), insects invaded the air in numerous spectacular forms that had far greater chances of survival than they would have now, for there were no other flying forms to prey on them.

The earliest flying vertebrates did not appear until about 120 million years later—that is, some time during the Jurassic period. This period and the Cretaceous witnessed the development of the flying reptiles, which are grouped together in the order Pterosauria. The first flying mammals (bats), belonging to the order Chiroptera, first appeared during the Eocene epoch of the Tertiary period, approximately 50 million years ago.

Reptiles and mammals made use of similar kinds of adaptations in their efforts to fly; the former had a thin membrane attached to one enormously lengthened digit of each forelimb, while the latter had a membrane supported by all but one digit. Even though these animals were good fliers, they never attained the aerodynamic perfection of birds. Moreover, a bad cut on a wing membrane would tend to disable a bat; a similar occurrence is scarcely possible in the case of a bird, whose feathers are independent of one another.

Birds constitute a class of vertebrates mainly destined for flight. They are closely related to the Archosaurian reptiles—so much so, in fact, that birds have been called "nothing but glorified reptiles." What really distinguishes the birds from the reptiles is their feathers and their warm-bloodedness.

The avian skeleton retains a general reptilian structure. Certain modifications have resulted from the birds' particular

2

ARCHAEORNITHES, THE EARLIEST BIRDS—The earliest and most interesting remains of fossil birds were found at Solnhofen, Germany. This locality has a deposit of extremely fine yellow limestone that was laid down during the Upper Jurassic period (Kimmeridgian epoch) in what was either a shallow sea or a calm lagoon. The very fine grain of this deposit allowed the almost-perfect preservation of delicate structures that are not usually fossilized. This limestone contains imprints of dragonflies with the membranous wings still intact, and cephalopods complete with tentacles.

At Solnhofen in 1861 the imprint of a bird's feather was discovered. About 68 mm (about 2.6 in.) long, the feather was complete with a rachis, barbs, and barbules. In this way it was discovered that birds existed during the Upper Jurassic; their appearance remained unknown. However, in the same year a small skeleton (shown in relief in illustration 2f) was discovered. The skeleton was similar to that of a reptile in all respects—except for the perfectly clear imprints of feathers around the tail and forelimbs. This discovery was deemed sensational, and the animal was called *Archaeopteryx lithographica*. The find was purchased by the British Museum and was given the new name of *Archaeopteryx macrura*. It was studied as the missing link between birds and reptiles. In 1877, ten miles from the original discovery, a second fossil bird was discovered. This specimen, purchased by the Berlin Museum, was named *Archaeornis*. Because the two specimens had analogous features, they were later grouped together under the name *Archaeopteryx*.

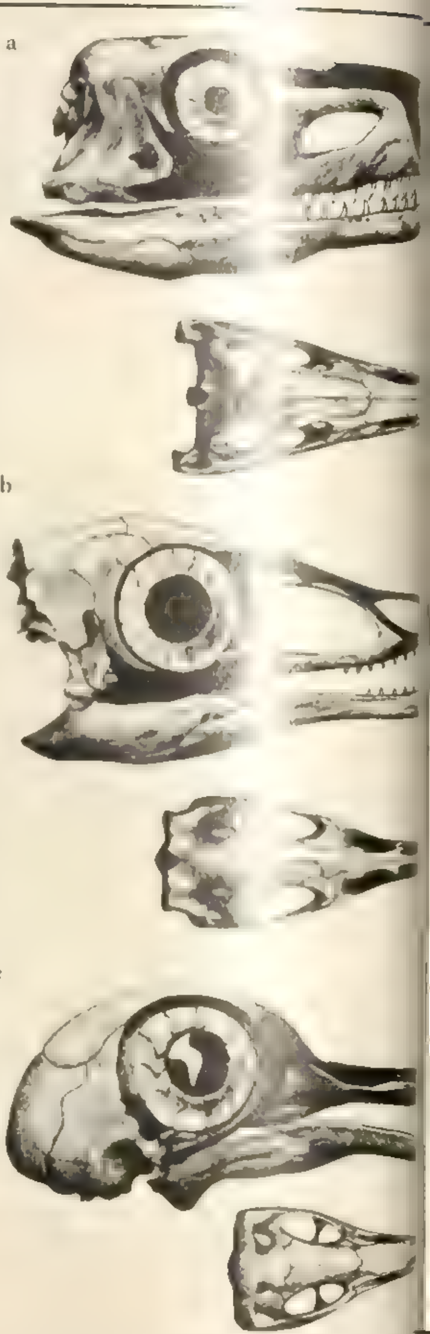
The skull of *Archaeopteryx* was compact, with many reptilian features, such as the wide preorbital, nasal, and temporal fossae, the numerous, almost cylindrical, short teeth in both jaws, the fenestration in the mandible (as in many primitive reptiles), and the complete sclerotic ring around the eye. Casts of the inside of the skull have also established that the brain had more in common with the brains of the reptiles than with those of present-day birds. The skull (illustration 2a), therefore, can be thought of as intermediate between that of the Pseudosuchian reptiles (*Euparkeria*, illustration 2b) and that of present-day birds (the pigeon, illustration 2c).

The body of *Archaeopteryx* also had reptilian features (illustration 2d). Moreover, the bones were not hollow. The skeleton of a living bird, the domestic pigeon (illustration 2e), is presented for purposes of comparison.

a

b

c



e

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f

The two specimens from Solnhofen demonstrate the phyletic descent of the birds from the reptiles and also prove that this development occurred as early as the Upper Jurassic.

Further traces of fossil birds of the Jurassic were found at the beginning of the twentieth century in a rocky formation near Lérida in Spain. This formation, also dating from the Kimmeridgian epoch, was, therefore, of the same age as the yellow limestone of Solnhofen. However, these traces were not considered completely trustworthy, and it is only recently that a fossilized feather was found to prove that primitive birds must have had quite a considerable wingspan—even in Jurassic times.

manner of adaptation for flight. Some bones, for example, such as parts of the skull, the cervical vertebrae, the humerus, and the femur, are hollow and hence very light. The forelimbs that support the flying mechanism are highly modified, while the long reptilian tail has disappeared. The sternum has been transformed into one broad bone with a kind of keel down the middle; the latter facilitates the attachment of the powerful muscles required for flying.

3

THE ORIGIN OF THE FIRST BIRDS: THE PROAVIS — Beginning with the assumption that *Archaeopteryx* was a bird, a number of scientists set about the task of working out the manner in which birds evolved. In the process, they tried to establish what the predecessors of *Archaeopteryx* looked like. In this way many reconstructions came to be made of the primordial bird, which was called *Proavis*. To this day *Proavis* has never been found in fossil form.

Some scientists think that *Proavis* was a tree-dwelling quadruped descended from a small reptile that sprang from tree to tree, using the claws of its forelegs to grasp tree limbs and branches. Two fingers of its foreclaw thus became lengthened and formed the structure that would carry the wing. Other scientists think that this animal developed a pelvic wing—formed by the rear limbs—that was intended to help it glide from the treetops.

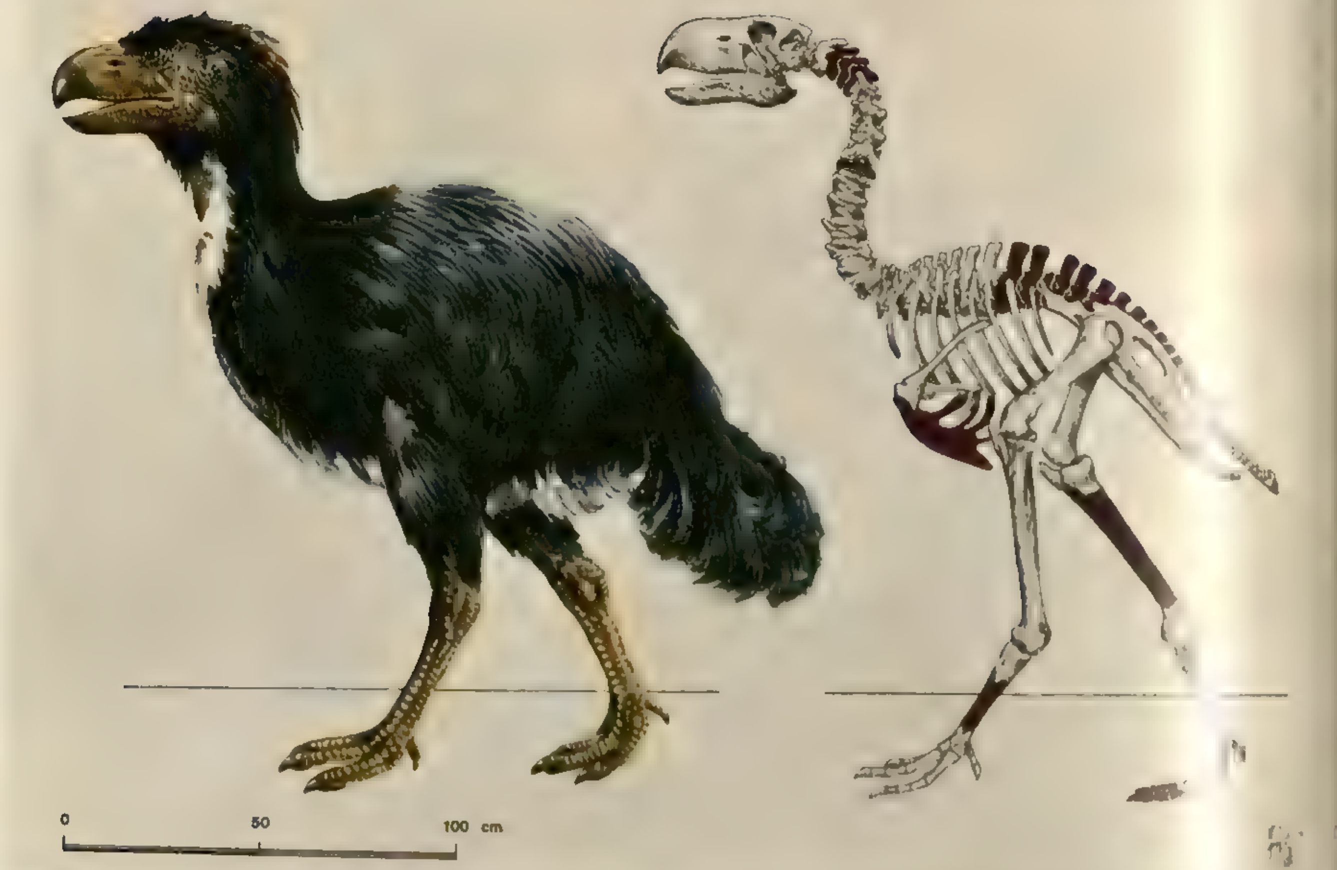
In this illustration, *Proavis* is represented as half-reptile and half-bird, with a body covering of scales and feathers and a head like a lizard.

4

HESPERORNIS REGALIS—This bird has been assigned to the subclass Neornithes, to which belong all birds except *Archaeopteryx*, which is classified in the subclass Archaeornithes. The Neornithes possess several distinguishing features, including small tails, a well-developed sternum (sometimes with a notable keel), and reduced and fused metacarpals. *Hesperornis*, of which a large number of specimens have been discovered, is probably the best known of the fossil birds.

In *Hesperornis*, primitive features were combined with a high degree of specialization. On the primitive side, *Hesperornis* had many teeth in its upper and lower jaws, while its horny beak (a characteristic of more highly evolved birds) was perhaps in the process of formation. On the other hand, this bird was highly specialized for an aquatic life. It was a large animal, somewhat more than 1 m (a little over 3 ft) from the tip of its skull to the end of its tail. Its main features were a weakness of the shoulder girdle and a reduction of the sternum, which had no keel. The practically nonexistent forelimbs doomed *Hesperornis* to a flightless existence. The hind legs, on the other hand, were so well adapted to swimming that they were probably not of much use for moving around on land.

5



BIRDS OF THE TERTIARY—By the beginning of the Tertiary period the class Aves was already fairly well developed. In fact, of the more than 30 orders of birds in existence today, at least 14 were already present in the Eocene epoch.

One of the most unusual birds of the Tertiary was *Diatryma* (illustrated). It was a large bird of the Paleocene and Eocene epochs, whose remains have been discovered in North America and Europe. A running bird, *Diatryma* was one of the earliest examples of the ratites. Measuring more than 2 m (about 6 ft) in height, it had a strong, heavy skeleton, long, strong hind legs, and small, useless wings. Its large skull was equipped with a powerful beak that must have been an efficient weapon against the mammals of the time.

The Miocene formations of South America have yielded the remains of another large bird, *Phororhacos*, which was similar in appearance to *Diatryma*, but smaller—about 1.5 m (about 5 ft) in height. This bird, too, had a powerful beak and long legs. Like *Diatryma*, *Phororhacos* was a good example of adaptation to terrestrial life in a world that was not yet populated by flesh-eating mammals.

The hind legs resemble those of the dinosaurs, while the skull, with its large eye sockets and well-developed cranium, differs from that of the reptiles (although the structure might be derived from that of the Archosauria). There is a single occipital condyle, but no pineal aperture. Like the reptiles, the birds lack a secondary palate, but their nostrils are far back. The most primitive birds were equipped with teeth, which disappeared in the course of evolution.

EVIDENCE OF AVIAN EVOLUTION

Fully 50 million years passed between the Upper Jurassic, the time when the primitive *Archaeopteryx* lived, and the Upper Cretaceous, in whose rocks traces of other fossil birds have been discovered. During this long span of time, the birds must have developed extensively, even though paleontological evidence of such a development is lacking. Nevertheless, the birds of the Cretaceous were clearly far more advanced than their Jurassic ancestors. Most of the paleontological evidence consists of skeletons discovered in muddy marine deposits; in all likelihood the preservation of these specimens was due to rather unusual factors. A bird skeleton is fragile and deteriorates rapidly. It can be adequately preserved only if it is immediately covered by sediment in such a way as to protect it from external agents of destruction. This sediment exists only in a marine environment.

Despite these difficulties of preservation, fossil birds dating from the Upper Cretaceous have been found in the United States, South America, and England. Two specimens from the Cretaceous rocks of Kansas, *Ichthyornis* and *Hesperornis*, are the best known.

At the beginning of the Tertiary many groups of birds now living were already represented. The class Aves was sufficiently well differentiated for scientists to distinguish between the good fliers, the Carenatia, and the Ratites, which had lost the ability to fly but were good runners. Some of the latter have become extinct in historical times, but they were well documented by ancient writers.

FAUNA OF THE PALEOCENE AND EOCENE EPOCHS | animal life in the early Tertiary

The Paleocene and Eocene epochs together encompass the first 27 to 32 million years of the Tertiary period. The significant features of faunal development during these epochs can be traced among the higher organisms. In brief, the fundamental characteristic of the Paleocene and Eocene was the evolutionary expansion of the mammals; so rapid was this development that the mammals required only about 20 million years to reach a high point of perfection, coupled with a considerable degree of specialization. By way of comparison, the reptiles developed more slowly during the Mesozoic era, taking more than 100 million years to reach their zenith.

Even though the higher animal forms are more important, the world of lower organisms also has several points of interest. Geologically speaking, a very short time has elapsed since the end of the Eocene, and two factors have provided scientists with an abundance of materials for study. The first is the factor of fossilization: fossil remains from the early Tertiary are not only plentiful, but also are remarkably well preserved. The second factor is the widespread exploration for oil, which has resulted in the discovery of many of these well-preserved fossils.

Fossils of certain mollusks with calcareous shells still contain much of their original material; in some cases, they retain even their colors. Ordinarily, with the passage of time—hundreds of millions of years, for example, or merely tens of millions of years—such remains are altered along with all the other minerals comprising the rocks in which the remains are imprisoned. They are transformed—some slightly, some greatly, and some so much that they disappear altogether. Many ancient rocks have undergone such changes that they have vanished; and with them have vanished any fossils that they may have contained.

Certain fossil specimens of lower animals from the Paleocene and Eocene often appear so realistic that a layman might well have difficulty determining whether they are really fossils or present-day specimens that had died recently. The fossils of the early Tertiary, therefore, are exceedingly rich and informative.

The evolution of the lower organisms proceeded slowly, but these early Tertiary animals existed in groups of genera numbering in the tens and even the hundreds. This type of development provided many guide or index specimens that are valuable because they enable geologists to divide the various rock formations stratigraphically.

The Paleocene and Eocene epochs were characterized by an extensive quantity of discoid foraminifers, known as nummulites, and many other organisms of small or moderate size that have left their traces or the imprints of their shells in the rocks, thus enabling geologists to measure the passage of geological time in areas once covered by seas. This lower fauna was also a factor of the greatest importance in the development of other aquatic animals that fed on them.

THE HIGHER ANIMALS

The fauna of the Paleocene and Eocene epochs included practically all the groups existing today, although most of them, because of their particular stage of evolution, were somewhat different from the animals of the present. Significantly, the primates were represented in the early Tertiary by the lemurs only; other primates evolved much later in the Cenozoic era.

The fauna of the Paleocene and Eocene is clearly distinct from the fauna of the preceding periods. During the Mesozoic era, the fauna evolved from one period to another with remarkable continuity. The reader need think only of the evolution of the turtles, dinosaurs, flying reptiles, and plesiosaurs—between this fauna and that of the early Tertiary, there is an enormous gulf. Of the once-dominant reptiles, only the crocodilians and turtles remained in any great numbers. The animals of the Paleocene and Eocene were destined to evolve throughout the various epochs of the Tertiary period at a steady pace, until two factors brought about a profound change. The first was a succession of four glaciations or "ice ages" during the Quaternary period. The second was the coming of man.

On dry land, the appearance of the mammals was followed by their very rapid evolution, specialization, and distribution. From a paleontological point of view, it is interesting to follow this evolution and to try to discover reasons for it. From the geological and stratigraphical points of view, on the other hand, it is most useful to observe the differences between one stratum and another and to date the various formations, even though on a relative time scale only. In fact, the mammals are sometimes used as guide fossils in places where local conditions were such as to form a thick sedimentary layer that imprisoned the remains of mammals in evolution. This happened, for example, in the famous Paris Basin.

CHARACTERISTICS OF THE MAMMALS

What reasons can be found for the sudden and complete diffusion of the mammals? This question cannot be answered in any great detail, but it is possible to point out the advantages that the anatomy and physiology of the mammals gave them in the struggle for existence in the Tertiary period. These advantages, however, are insufficient to explain the predominance of mammals in the Eocene epoch.

Each era has produced a fauna in which the speed of evolution was characteristically slow or fast. The earliest eras gave rise to forms of life that

evolved very slowly. For example, the echinoderms and the sponges evolved very slowly and chiefly through the modification of a few details; it is unlikely that the future development of other forms of animal life may cause these organisms to vanish.

The Mesozoic era gave rise to the saurians, whose evolution required a relatively long span of time. In the Tertiary, the mammals developed in a relatively short span of time, chiefly through the avenue of specialization.

Climates, environments, fauna, and flora have always been variable throughout geologic time, and the least specialized animals have been affected by this variability much less than the highly specialized forms. In very ancient times animals exhibited very little specialization, but in the Paleocene and Eocene, the mammals underwent extensive specialization. Whenever an environment was favorable, an animal that was specialized so as to take advantage of the favorable factors spread very quickly. However, if the environmental conditions changed more rapidly than the species could adapt to them, that species was fated to become extinct. This explains the rapid appearance and equally rapid disappearance of mammalian species throughout the entire Tertiary period.

What are the general characteristics of the mammals? In the first place, they are warm-blooded animals; that is, their body temperatures are independent of the environmental temperature. Therefore, mammals can adapt themselves readily not only to the temperate zones, but also to areas subject to great variations in climate.

A second characteristic of the mammals is their heightened sensitivity, as compared with other animals. This sensitivity gives them a great advantage in hunting, especially if they are carnivores.

Finally, in reproduction, the mammals are viviparous. Reproduction by means of eggs is relatively primitive, suited only to less highly evolved forms of life. In an egg there is an enormous loss of

1

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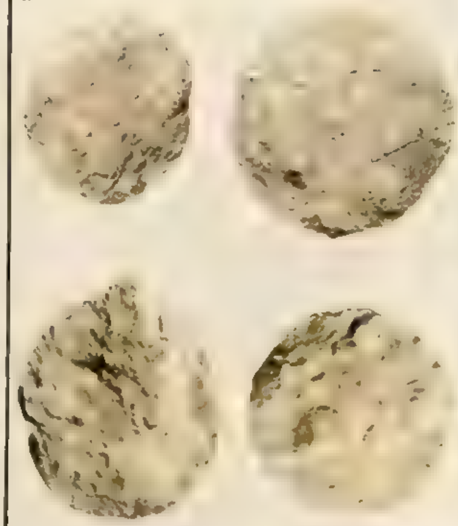


b

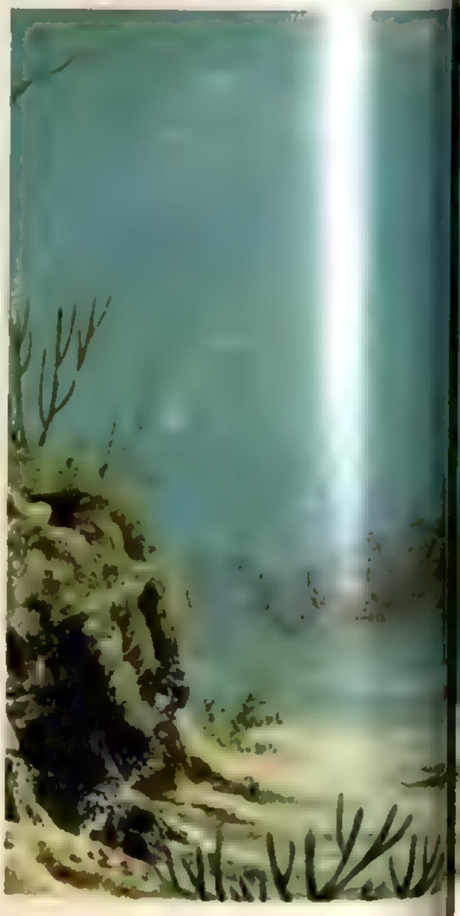
THE EOCENE SEA—This illustration was designed to provide the reader with some idea of the appearance of the waters and the bed of the sea during the early parts of the Tertiary epoch. Emphasis has been placed on the large number of lower animal forms shown in the foreground. The corals were forming large rocks and were giving evidence of their talent for building, which, as they demonstrated during the Triassic period, can result in the production of entire mountains. However, during the early Tertiary, the corals were living in an environment that was less favorable than that of the Alpine seas in Triassic times; for this reason, the coral constructions of the Paleocene and Eocene are considered of minor importance.

The foraminifers were distributed here, there, and everywhere, but they should be examined in detail for, otherwise, being very small, they might be mistaken for innumerable other planktonic organisms.

Together with other shelled animals, a number of species of echinoderms are shown on the sea bed: *Echinolampas calvimontanum* of the Eocene, and *Conoclypeus* and *Schizaster*. These organisms had scarcely changed form since they first appeared in the paleontological record. *Arca*, *Cardita*, *Lucina*, and *Cytherea* were among the prominent pelecypods; the oysters, also pelecypods, were destined to diversify until they attained gigantic proportions in the Pliocene epoch.

Natica, *Velates*, *Cerithium*, *Terebellum*, *Cyprea*, *Conus*, and *Pleurotoma* were some representative genera of the great variety of gastropods. This type of animal, which has been described by reference to remains found in European basins, was fairly constant in the waters of all oceanic basins.

2



LARGE N[illegible]LITES OF THE EOCENE—The nummulit[illegible]mbers of the genus *Nummulites*) wer[illegible]acteristic lower organisms of the early [illegible]y period. The name assigned these di[illegible]aminifers is derived from the Latin wo[illegible]in, and the nummulites indeed resembl[illegible] The specimens shown in illustratio[illegible] completely fossilized, showing tota[illegible]tion of the original material by the [illegible]e of the rock in which they were en[illegible] For this reason, the fossils were de[illegible]from the rock with great difficulty; th[illegible] illustrated have been slightly affected [illegible]mall amount of rock adhering to the fo[illegible]aces.

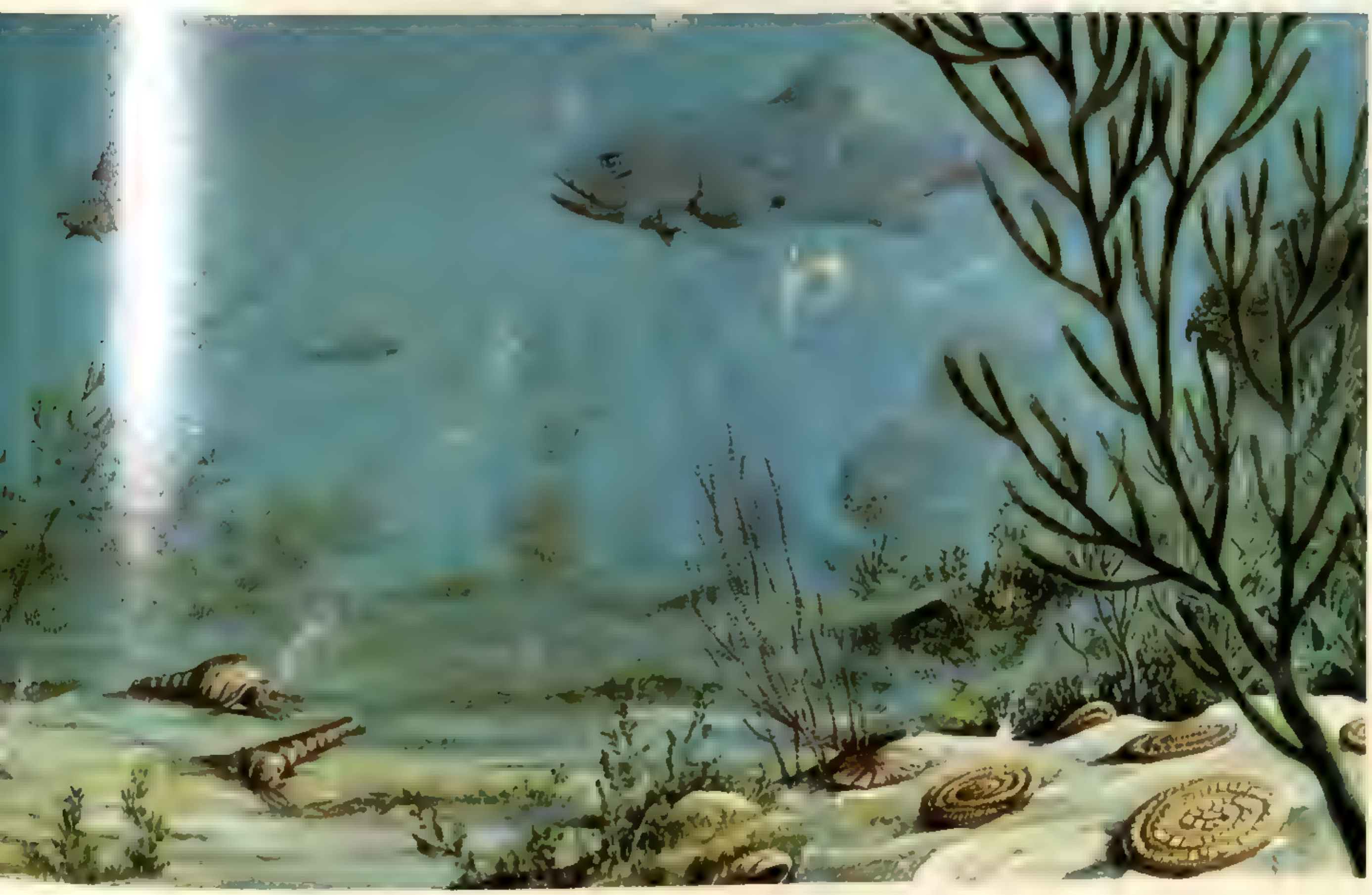
Numm[illegible]e usually found in limestone; rock full [illegible]n fossilized remains is called nummuli[illegible]stone. A section cut through nummul[illegible]stone reveals a large number of numm[illegible]rammed into the surrounding rock. Th[illegible]arranged in every possible direction, [illegible]st lie more or less parallel to one anot[illegible] these foraminifers, being flat, naturally were deposited in horizontal layers.

Illustration 1b shows a nummulitic limestone as it appears when it has been split and polished; an abrasive polish can be used to obtain such a section. The limestone is split in the hope of uncovering fossils; the surface is then burnished. As long as this surface remains the slightest bit dull, no sign of a form will appear. With a high polish, however, animal forms will appear.

Another interesting experiment involves the grinding of both sides of a thin layer of nummulitic rock (gluing it to a rigid base to keep it from breaking) until it is about 0.3 μm (microns) thick. It is then almost transparent, showing all the sections of fossils that it contains. This method of observation is particularly useful in the case of microfossils.

Although illustration 1b shows nummulites only, certain associations are much more complex. In Paleocene deposits, members of the genus *Nummulites* are often associated with *Orthophragmina;* in Eocene deposits they are associated with *Axilina*.

Italy has a great many nummulitic limestones, the most interesting being those of Monte Bolca, near Verona. This formation has a famous deposit of fossil fishes, forming a kind of petrified Eocene aquarium, complete with appropriate vegetation mostly of an offshore type. The Monti Sibillini, the Gran Sasso, and the Maiella are other examples of nummulitic limestones, which may be found from the Alps through Iran as far as China.



3

THE FAUNA OF THE EOCENE—In this illustration of the Eocene landscape, aquatic animals are not shown. During the Eocene, however, a small rodent living on the seashore began to specialize in swimming. In time, through the process of natural selection, this animal became the best swimmer of all—the dolphin.

The air in Eocene times was full of many species of birds, from which the present-day species would soon evolve. *Diatryma* e was similar to certain types of birds that have become extinct during the present period, the Quaternary. This bird was large, heavy, about 2 m (about 6 ft) in height, and was unable to fly because of its great bulk and small wings. Judging from its enormous beak, this resident of the American prairies must have been a fierce predator.

Many species of crocodiles lived along the riverbanks. A number of species of marsupials lived on land, even in Europe. Where the city

reproductive material, a loss that is permissible only when waste is not a critical factor. In addition, many eggs are eaten or otherwise destroyed before they have an opportunity to hatch. In any case, the entire system demands an environment with very favorable conditions if comparatively few specimens are to survive.

Among the mammals, the problem of survival of the species is solved by viviparity. Mammals give birth to perfectly developed young, which they then protect for quite a while, at least as long as needed for the young to turn into self-sufficient adults.

Nursing offspring is a highly specialized way of feeding young. The parent maintains its offspring in a manner that gives it the maximum independence from the environmental conditions.

Marsupials, which appeared early in mammalian history, use an intermediate technique, keeping the offspring in a pouch (marsupium) after its birth. This characteristic of marsupials may represent a halfway stage between the oviparous and viviparous methods.

From the Eocene onward, the continents began to break up and drift apart; America was separated from Europe and Asia; the Isthmus of Suez appeared; Madagascar was separated from

of Paris now is was a salt lagoon that slowly dried, forming a deposit by evaporation and enclosing the remains of the animals living on the shores of the lagoon. This evaporative deposit of the Paris Basin is a kind of fossil zoo that has been studied since the science of paleontology was in its infancy.

In *Phenacodus*, many mammalian features now belonging to different animals appeared in the same species, as though the teeth of a carnivore had been put together with the body of an herbivore and the legs of a running animal had been combined with the hoofs of a ruminant.

Most of the animals in this illustration were Eocene ancestors of modern animals: *Coryphodon* **a**; *Eohippus* **b**, ancestor of the horse, but about the size of a small dog; *Moeritherium* **c**, ancestor of the elephants; and *Oxyaena* **d**, ancestor of the hyenas. Ancestors of camels and swine also lived in the Eocene landscape.

Africa; and later on Australia became isolated. Such geological phenomena would not have had much importance in a world that was evolving slowly, but they played a vital part in the story of rapidly evolving animals. These phenomena led to the establishment of different fauna in the isolated blocks; apart from this, evolution proceeded quickly in some blocks and slowly in others. Therefore, geologists are sometimes confronted today with regions that are characterized by a highly developed and continuously evolving fauna, and with other regions in which fossils predominate or in which the animals seem to have been left behind by history.

The evolutionary explosion of the mammals must not be allowed to push other important phenomena into the background. For example, the birds also underwent a population explosion. Many species evolved; some were adapted to life on the shores, others to life in the open country, and still others to life in mountainous regions.

This general view of the Paleocene and Eocene landscape is insufficient to relate much about the variety or wide distribution of animal life during the early Tertiary, but it does demonstrate how these epochs differed from the preceding periods.

FLORA OF THE PALEOCENE AND EOCENE | plants in the early Tertiary

The turning point in the evolution of plant life occurred with the appearance of large numbers of angiosperms during the Cretaceous period. Throughout the Paleocene, Eocene, and subsequent epochs of the Tertiary, this evolution continued steadily and without surprises.

Comparison with developments in the Animal Kingdom is impossible, because faunal changes were enormous. The great reptiles disappeared at the end of the Cretaceous, while the mammals underwent a vast evolutionary explosion during the Tertiary. Nevertheless, fairly important changes in the evolutionary history of plants did occur during the early epochs of the Tertiary. In the first place, plant fossils have been found in great numbers. This is significant, because the fossilization of a plant is less probable than the fossilization of an animal. Tree trunks can be fossilized easily, but the leaves and other delicate parts of plants usually are destroyed before they can be preserved.

Paleontologists have discovered in deposits of Paleocene and later epochs perfectly preserved specimens of the delicate parts of plants. Some of the leaves have been so well preserved that they might have been taken from a contemporary collection of dried plants—except that, being fossilized, they consist of mineral substances. When leaves have been preserved in fine mud, much of the microscopic anatomy is recognizable.

Specimens of pollen have also been recovered from deposits formed during the Paleocene and subsequent epochs. These fossils are still too rare to serve as climate indicators or to provide statistical data concerning the extent of populations. Nevertheless, such fossils are useful in dating certain kinds of sedimentary deposits.

An examination of the flora is commonly used in reconstructing the climates of the remote past. For example, the nature of Tertiary flora indicates that the climate in most parts of the Northern Hemisphere was hot, almost tropical, throughout the Paleocene, Eocene, and Oligocene epochs. Toward the end of the Tertiary the climate turned colder and produced widespread glaciation in the Quaternary period.

Palms grew abundantly in Italy and throughout the whole of central Europe, thereby indicating that these regions had tropical or subtropical climates. The presence of many other plants typical of the tropics also bears witness to the high temperatures and heavy rainfall that must have characterized these regions during the early part of the Tertiary. In all likelihood, these conditions favored the development of new forms of life—angiosperms in the Plant Kingdom and mammals in the Animal Kingdom.

Climatic conditions in North America during the Paleocene and Eocene were quite similar to those in northern Europe, but slight differences in flora existed. The climate of North America may have been a little cooler than that of Europe. However, the fact that such a warm climate should have endured for such a long time—tens of millions of years—is remarkable. The Quaternary period, which followed the Tertiary, spans a much shorter time; yet the Quaternary was characterized by four intervals of glaciation separated by four intervals of relatively warm climate. During cold intervals, the sea withdrew from the land; during warm intervals, it again encroached on the land. Despite the alternation of hot and cold climates, Quaternary flora managed to adapt, changing periodically from plants characteristic of cold climates to plants typical of warm climates.

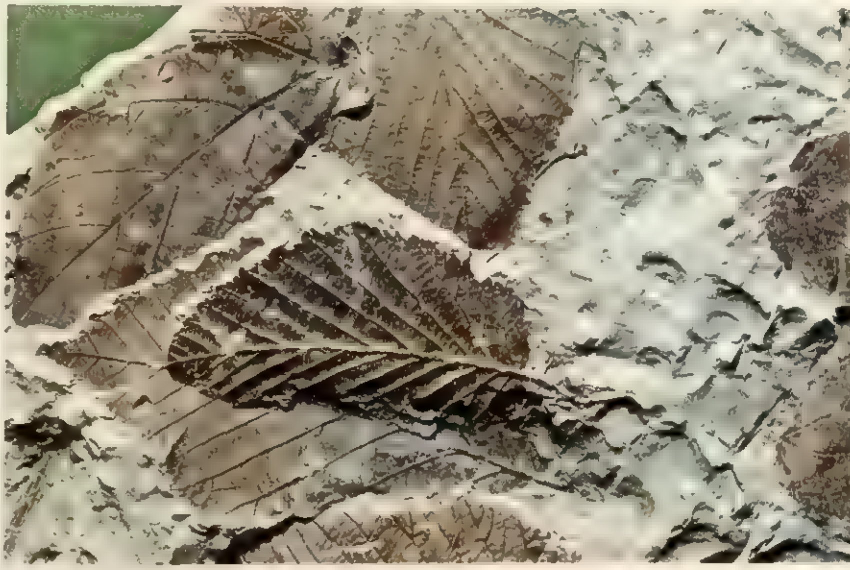
The unchanging nature of the climate during the early epochs of the Tertiary was, therefore, quite remarkable. These epochs provide paleontologists with their first opportunity to follow with absolute certainty an event occurring over a long span of time. Periods of glaciation, indicated by tillites (boulder clays), occurred during Precambrian times, but geologists have no way of determining how long they lasted. Perhaps other shorter intervals of glaciation also occurred, but these are lost in time. Today, plant fossils not only indicate how long the hot and cold climates lasted, but they do so with extraordinary immediacy.

Trees and plants are among the most significant and interesting elements of a

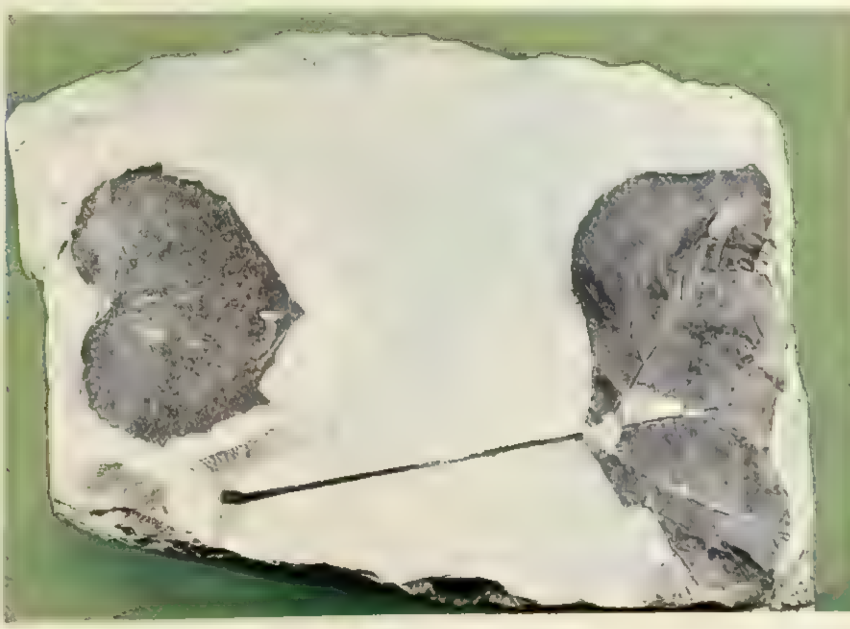
THE RICH FLORA OF MONTE BOLCA—The limestone deposits of Monte Bolca, near Verona, Italy, are notable for their excellent fossils of Eocene fish. This same region has also provided some fine fossils of coastal plant life, including this specimen, belonging to the genus *Latanites*.

A STORY FR[illegible] THE PAST—Some 60 million years ago a [illegible] of hazel trees lived undisturbed in [illegible] environment. Exactly where they lived ca[illegible] be determined, but it probably was no[illegible] from a river. When autumn came, the lea[illegible] from the trees and landed on mud that [illegible] been deposited by a small flood. The lea[illegible] stuck in the mud and began to dry. At th[illegible] ment, the land was again flooded gent[illegible] a gradual advance of the river waters. [illegible] distance from the banks of the stream [illegible] waters were still, but they contained sm[illegible] articles of silt and soil in suspension. [illegible] the flood waters receded, leaving a car[illegible] fine mud behind. This layer was as fine a[illegible] onto which the leaves had fallen. In this [illegible] the leaves of the hazel trees were entirely [illegible] sed in mud, from which the water slowly [illegible] porated. Later, the dried layers of mu[illegible] became impermeable to air; thus, the [illegible] es were perfectly preserved. Ever since, d[illegible] te rather intense geological changes, the [illegible] leaves have been protected from chemica[illegible] ration by water and air. Today, the mud [illegible] sing the leaves has consolidated into br[illegible] rock that splits easily when struck with a [illegible] gist's hammer.

Many rea[illegible] undoubtedly have strolled through the countryside in late autumn and have observed the freshly fallen leaves about their feet. Not all of these leaves are as perfectly preserved as fossil leaves.



THE ANCIENT OAK—Of the angiosperms common during the Tertiary period, the oak has one of the longest pedigrees. In fact, the earliest oak known dates from the Cretaceous period of the Mesozoic era. This illustration shows oak leaves fossilized in exceptionally fine mud; minute anatomical details have been preserved.



TWO FOSSIL LEAVES—These two specimens of dicotyledonous angiosperms are almost as perfectly preserved as if they had been dried the previous day. The rock has preserved the leaf structures so well that the microscopic anatomy can be traced without difficulty. The fossil leaf on the left is from a vine, while that on the right is from a plane tree.

landscape. The landscape of the early Tertiary was not totally unlike that of today—at least, it was much more similar to the present-day landscape than had been the landscape of previous eras. Many genera of present-day plants lived during the Paleocene and Eocene epochs, but the species were different. The plant life of the Tertiary period was itself characterized by changes in taxonomic and physiognomic composition as a result of the major climatic trends and fluctuations. The Paleocene floras include many extinct genera of angiosperms and some extinct conifers, but Eocene vegetation took on a more modern aspect. Paleocene floras from Belgium, France, Greenland, and various parts of North America have an archaic aspect because they are closely related to the late Cretaceous floras. Typically subtropical to tropical plants such as members of the moonseed family (*Cocculus*), the Icacinaceae (*Phytocrene*), and *Sabal*-type palms are known in the Paleocene of Cook Inlet, Alaska; and palms and cycads occur in the Paleocene of Kupreanof Island in southeastern Alaska.

The Denver flora of the Colorado area gives evidence of climatic zonation when contrasted to that of central west Greenland. The palms, the abundant and diverse laurels, and the menisp s (woody climbers) of the Denver flo re absent in the Greenland flora. All t floras are essentially of lowland ori however, and they have many ele in common. The Paleocene flora, t, has the most cosmopolitan aspect ny of the Tertiary floras.

As the climate warmed Eocene, many of the Paleocene pla came extinct; and others evolve meet the changing environment. Th y Eocene London clay flora cont uits and seeds of extinct genera, e overall character of the vegetat imilar to that of present-day Mala

THE TROPICAL LANDSCAPE OF THE SEASHORE—This illustration attempts to reconstruct the appearance of the seashore during the early part of the Tertiary period. Palm trees reminiscent of tropical islands fringed the beaches. Seaweeds typical of hot seas thrived under water, while o distance from the water exist lophytes (algae and fungi) th and some rtain tha live today.

MAMMALS OF THE PALEOCENE AND EOCENE | a survey of some representative forms

1

A SMALL ORDER—This is a photograph of the skull of *Tillotherium trogosus*, a mammal belonging to the small extinct order Tillodontia. The well-developed second pair of incisors are noteworthy.

The mammals were the dominant animals of the Paleocene and Eocene epochs—and, indeed, of the entire Tertiary period. Their particular significance in the early epochs of the period derives from the fact that they completely replaced the reptiles as the masters of the land.

Paleontologists have had to make a very detailed study of the primitive mammals of the Paleocene and Eocene ages in order to identify the progenitors of modern mammals. Just as studies of Mesozoic fauna provide clues that heralded the appearance of mammals, studies of Tertiary mammals provide landmarks pointing to the appearance of intelligence, if not to the appearance of man himself. A clearer understanding of how intelligence evolved can be obtained through a detailed study of the later epochs of the Tertiary. During the Paleocene and Eocene, however, mammals were beginning to evidence developing intelligence. For one thing, in many mammals the capacity of the skull and the weight of the brain were increasing; in a number of mammals, the brain had already developed many convolutions.

Another important development was the appearance of the hand, but this morphological feature was not particularly marked in the early part of the Tertiary; it became more apparent in subsequent epochs.

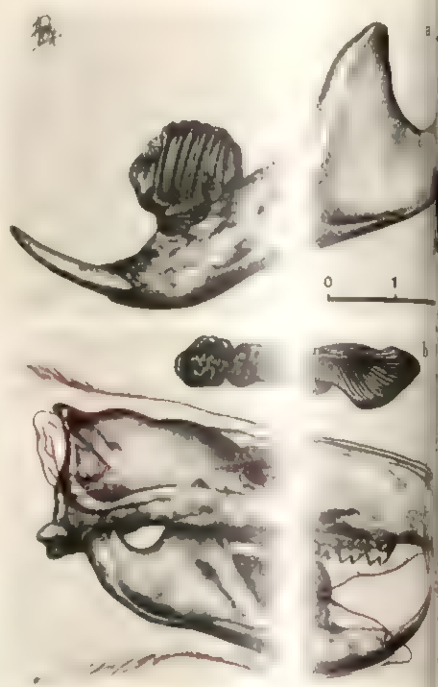
The Paleocene and Eocene were epochs in which some small mammals began the transition from terrestrial to aquatic life; in the course of time, these animals would evolve into forms adapted for life in the sea. In time the cetaceans (whales, porpoises, and dolphins), for example, would become as well adapted to ocean life as the ichthyosaurs of the Mesozoic era; the cetaceans would become rivals of the fish and other aquatic animals. Some cetaceans would become the largest animals ever to live on the Earth, exceeding in size even the giant dinosaurs of the Jurassic and Cretaceous periods.

Mammalian forms of the Paleocene and Eocene were very similar in both North America and Europe. Difference in the two faunas may be explained by the fact that mammals, because they are highly specialized, have always been unusually subject to mutation. The swiftness of mutation facilitates the use of Paleocene and Eocene mammals as guide fossils; in other words, mammalian remains are often used to date the various stratigraphic levels of Eocene formations.

2

THE END OF A CAREER—The multituberculates constituted an order of mammals that originated during the Late Jurassic and survived into the Paleocene epoch of the Tertiary. The fact that these animals survived into the Tertiary proves beyond doubt that their disappearance cannot be ascribed to some catastrophe occurring at the end of the Cretaceous. (The disappearance of the great reptiles has often been attributed to such a catastrophe.) Indeed, the multituberculates experienced no break in continuity, no sudden decrease in numbers between one epoch and the next; they merely underwent a gradual decline over a long span of time.

The lower jaw shown in illustration 2a belonged to *Neoplagiaulax*, a European multituberculate. The upper and lower jaws shown in illustration 2b are those of an American representative, *Ptilodus*. Remarkable resemblances exist between the two: the lower jutting fangs are almost of equal length; the huge, grooved premolars are identical in size, proportions, and position; the upper teeth, while much smaller, are similar in shape to those of a modern mammal. The skulls themselves were small. In fact measurements of skulls discovered intact reveal that the brain of this primitive mammal was unusually small, scarcely more than a bulge in the spinal marrow. The European specimen came from the famous Paris Basin, where multituberculates lived along with a great variety of animals studied by the French anat tologist Georges Cuvier (1 t and paleon- 1832).



3

THE MARSUPIALS—The marsupials (pouched animals) constituted a group of mammals characteristic of the Paleocene and Eocene epochs. At their peak, the marsupials numbered nearly 100 genera, but few representatives of the order Marsupialia exist today. Most living marsupials inhabit Australia; a few genera reside in Central and South America; and one species (the opossum) lives in North America. These modern marsupials may be considered living fossils.

Cuvier studied *Didelphis*, whose fossil he discovered in the chalk deposits of Montmartre, and took great pai specimen. The animal is sh size its similarity to modern tration 3a shows the cha teeth and clearly indicates portion of the skull was dev This aspect of mammalia stressed because in the c cranial capacities of mamm idly. Illustration 3b shows t of *Didelphis* were not so ro the Australian kangaroos o period. drawing the e to empha- upials. Illus- stic set of small pro- o the brain. rphology is of time the anged rap- e hind legs as those of Quaternary

a

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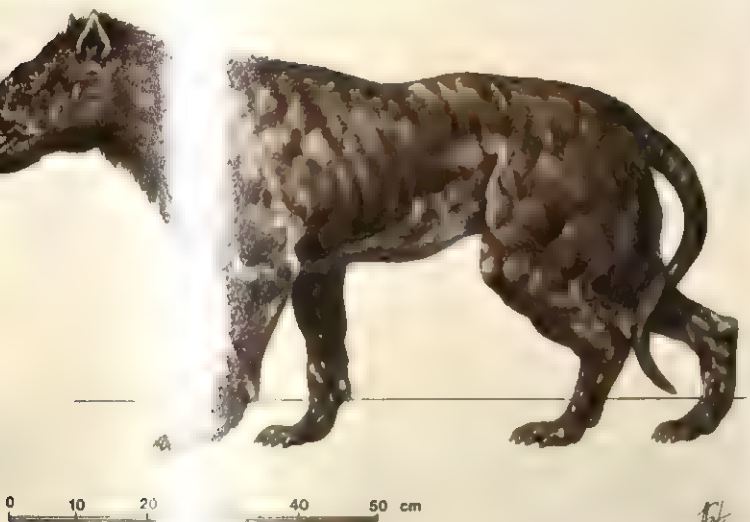

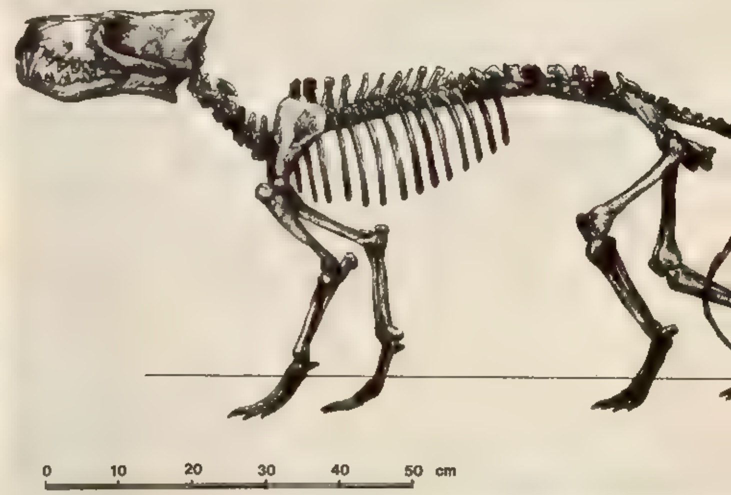

THE APPEAR[illegible] [illegible]F THE CARNIVORES—The earliest [illegible] [illegible]s somewhat resembled the modern h[illegible] [illegible]r fossil remains enable scientists to tr[illegible] [illegible] evolution of their skulls and particularly their teeth. *Hyaenodon*, illustrated in these reconstructions, was a member of a rather primitive family of carnivores. Representatives of the group had heavier bodies than present-day carnivores, and generally had long tails. They were less agile than their contemporary counterparts, and their claws were not retractable.

b

5

THE FIRST SWINE—The skull illustrated belonged to a primitive member of the swine family. The group evolved and specialized rapidly during the Tertiary. Another example of rapid evolution and specialization was *Moeritherium*, progenitor of the Proboscidea (elephants), which appeared during the latter part of the Eocene.

6

PROGENITOR OF THE CAMEL FAMILY—An interesting head of a dynasty was *Protylopus petersoni*, the first member of the camel family. This animal did not resemble modern camels, as it was small as a fox and humpless. The teeth of this protocamel were archaic; its incisors were separate, whereas representatives of the family had incisors joined to form a single crown along with the molars and premolars.

The first camels appeared late in the Eocene epoch, but evolved very rapidly.

THE OLIGOCENE EPOCH | a short, but signi ant, chapter in Earth ory

The Oligocene epoch of the Tertiary period covered a relatively brief span of time—about 11 million years—but produced many outstanding phenomena to pave the way for the Quaternary. Impressive orogenic events took place during the Oligocene; biologically, its flora and fauna came increasingly to resemble those of today, and mammals flourished. Mastodons and rhinoceroses developed at this time and the primates took a step forward with the appearance of the first creatures with hands and the tendency in certain species toward an upright posture.

The appearance of the hand would in itself be enough to mark the importance of the epoch. The brain, which had been growing during the Eocene epoch, now became of overwhelming importance. The development of the brain had taken place in a number of basic stages. The first occurred in the firs ulticellular creatures when they dev d an embryonic nervous system (the smallest marine creatures ne a nervous system to help them find l and flee from danger.) However, l progress took place until larger o ms developed; these needed a rud ry intelligence to enable them t pete with one another. A third sta s reached when animals first left th o conquer

GEOGRAPHY OF THE OLIGOCENE—The landmasses of the Oligocene might seem very different from those of the present day; but those parts of the masses that, although underwater, were integral parts of the masses must also be considered; these are the continental shelves. Evolutionary tendencies were also at work. The area of the present Mediterranean was still joined to the western Indian Ocean, but in the course of the Oligocene this link was destined to disappear.

In the Far East, the geosynclines, still features of those deep seas, had taken on the forms they have today with a few very minor changes. Madagascar was still joined to Africa but at the end of the Oligocene it separated from the vast bulk of the continent. This process of separation was temporarily halted during the great glaciations of the Quarternary, when the seas regressed considerably all over the world.

The most important geographical features of the Oligocene were those connected with the separation of Europe from North America. At this time the Atlantic Ocean came into being as a whole; previously it had been limited by the land bridges between Africa and South America and between North America and Europe. The geography of the American continent, especially the central areas, was very complex and very different from what it is now. The Andes were subject to an orogenic movement that went on throughout the epoch but never reached any great intensity. The Rocky Mountains were stationary.

Great orogenic events took place in Europe during the Oligocene. The Pyrenees and the Swiss Alps were being built up. The Alpine orogenesis paused from time to time; this great chain of mountains rose from sea level in a number of distinct phases with considerable consequences for the geology and geography of the Oligocene. These mountains rose from a sea that had been relatively deep, and they were elevated to a considerable height of some thousands of meters. The crests thus formed gave a completely new look to the geography of the mid-European sea. The Alps supplied a great deal of sedimentary material, because in a young morphology erosion is at its most intense. Thus were formed deposits composed of large fragments accumulating at the mouths of short streams rushing down to the sea out of the young mountains. Finer deposits were nearly always formed a long way from land. The coarse sediments originally eroded in the Alps and deposited in the sea near the coastline are still so large and well preserved that it is possible to determine in which part of the Alps they originated and how far they were carried before being dropped into the sea. In som ments it is even possible to determine rock fragments were the result of ero d the jour-

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The specialization of mammals stimulated increasingly effective use of the brain. The development of hands along with the brain paved the way for the evolution of an entirely new species—man—in which intelligence became the dominant weapon in the fight for survival. Intelligence provided artificial conditions of adaptation that physiology or the environment had not provided naturally.

UPPER OLIGOCENE	Aquitanian Chattian
MIDDLE OLIGOCENE	Rupelian
LOWER OLIGOCENE	Tongrian

SUBDIVISIONS OF THE OLIGOCENE—The Oligocene lasted for about 11 million years and can be subdivided stratigraphically into three or four ages, corresponding to the number of levels of deposits. The lower levels, bordering on the oldest rocks, are easy to establish; for example, changes in the composition of foraminifera are solid clues. However, such division is far from clear from a petrographic point of view. In the upper limits in Europe, there is uncertainty about the rock beds of the Aquitanian age. French geologists ascribe them to the Oligocene, while Italian scholars place them in the next epoch, the Miocene. The confusion stems from the complicated state of European geography. During the Oligocene the continent was broken up, dry land and seas alternating over its surface; some of the seas transgressed and others regressed. It is, therefore, difficult to draw an exact map of the age of deposits.

Shown is the European division into three ages, but the disputed Aquitanian is also included. In the European subdivision different levels are named after geographical areas of which they are especially characteristic. The American and Asian systems favor the terms Lower, Middle, and Upper for Oligocene rock units.

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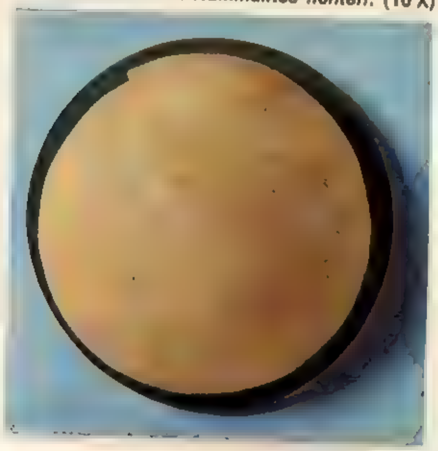
The sea that stretched from northern Europe to the Indian Ocean was drying out in the Oligocene; it was very shallow.

THE LANDSCAPE OF THE OLIGOCENE

During the Oligocene epoch, flora and the appearance of the Earth's landscape continued to develop much as they had during the preceding Eocene epoch. For example, the present continent of Europe was still a patchwork of shallow seas and recently emerged low-lying land.

Orogenesis cast up a number of mountain ranges. The Mediterranean basin had changed little for 10 or 20 million years. In earlier epochs great changes had occurred; instead of shallow seas there were geosynclines even over areas where mountains now stood, some of which were formed when a warm zone replaced a glacial one, or vice versa.

A SURVIVOR—Among the lower fauna of the Oligocene was *Nummulites*, an organism also common in the preceding epoch. These animals were no longer evolving in any particular way or at any speed. Although the species was no longer sensitive to evolution, it was extremely sensitive to its surroundings. Apparently insignificant factors in changes of climate, such as the salinity of water or the trace elements water contains, can lead to the disappearance of one species or to the appearance of others; it can also cause changes within a species, as happened to *Nummulites*. Thus the different stratigraphical levels can be marked off by observing the species and subspecies within them. The illustration shows a reconstruction of *Nummulites fichteri*. (10 X)



During the Oligocene, the most important changes were biological; some of these were of basic importance to many forms of life—above all, the higher animals, the mammals. A summary of events would include the disappearance of a number of species that had thrived during the Eocene, the appearance of new species, and the evolution of certain families that are still in existence today. Of exceptional significance was the appearance of ancestral pigs and apes.

Oligocene deposits of freshwater, brackish, marine, and terrestrial origin include sands, sandstones, marls, grits, shales, limestones, conglomerates, lignites, and volcanic materials. Thickness varies from a few hundred feet, as in parts of France, to more than 3,000 m (about 10,000 ft) in Oregon, Washington, northern South America, and Burma. Although the deposits were mostly laid down in shallow water or on land, in Oregon, Washington, Colombia, and Peru, the fossils indicate a deepwater marine environment of several hundreds to possibly several thousands of feet in depth. In northern Germany and the Lake Aral region in western Asia, the sea gained ground; but in most places the seas were less extensive than in the Eocene and the succeeding Miocene epoch. In the early Oligocene, the Bering Sea land bridge was elevated; allowing for a considerable terrestrial faunal migration between the old and new worlds. Near the end of the epoch, the ancient Tethys Sea began to fragment; and marine connections between the Mediterranean and the Indo-Pacific region were broken. In the Rocky Mountain area and in parts of France, lake and terrestrial deposits were formed. There was extensive volcanic activity in the high plains and Rocky Mountain areas of the United States and in the northern Andes of South America.

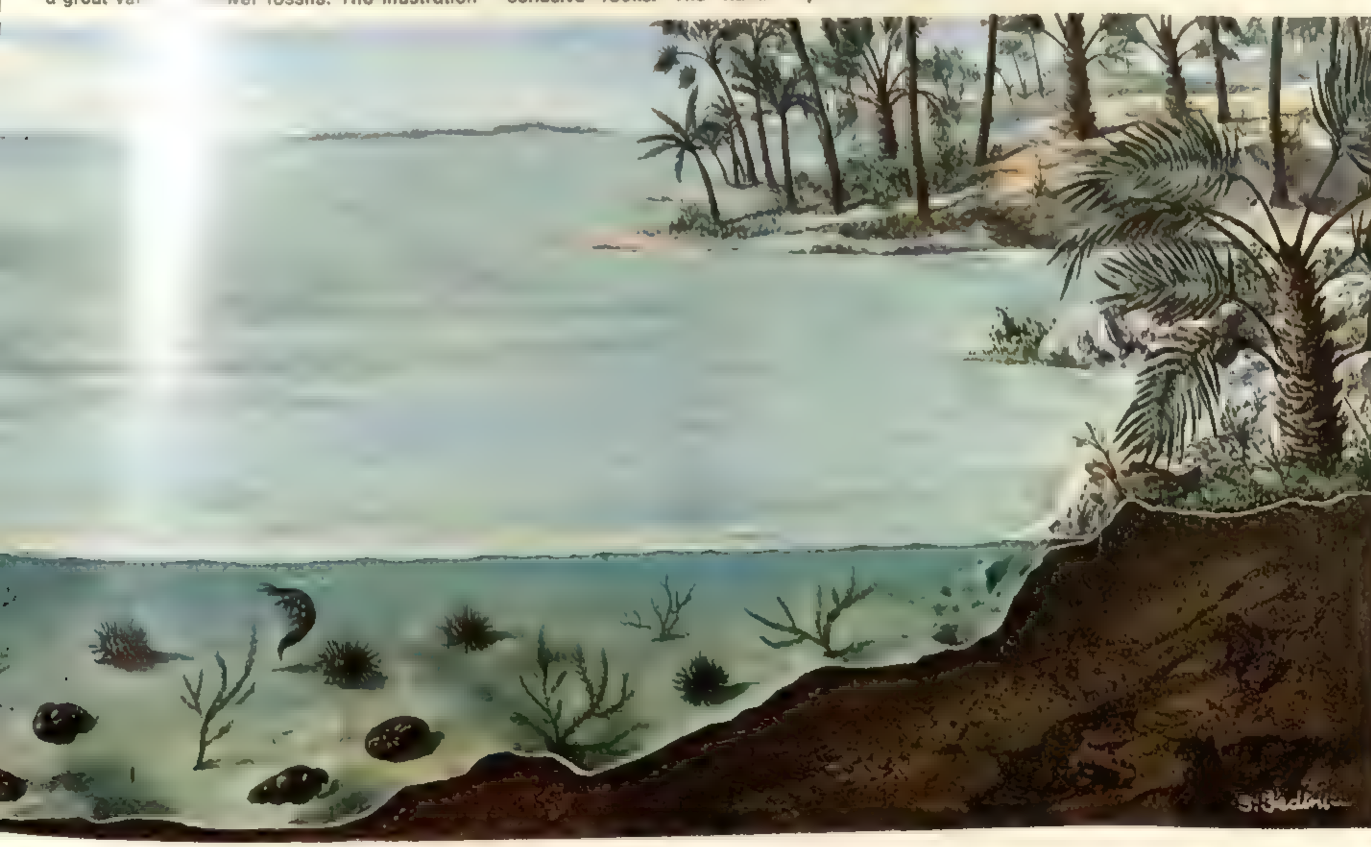
THE FLORA OF THE COLD AND TEMPERATE ZONES—Because the flora of the Tertiary period was composed of plants much like those of today, the climates of those times can be deduced with a fair degree of accuracy. It is more difficult to reconstruct the climatic conditions of earlier times; at best this can only be done on a continental scale. For the Oligocene it can be done with reasonable accuracy for areas as well as those of the Alps, the Apennines, or the southern coast of France. The task becomes even easier for the early Quaternary because specific climates can be determined by examining deposits of pollen.

The flora indicates that the Oligocene climate was considerably colder than in earlier epochs, which were decidedly tropical. During the Eocene the European coasts were fringed with palm trees as are the coasts of Africa today. This was the case even in areas that now lie north of the Alps. Although the Oligocene climate featured a gradual cooling, temperatures did not fall below today's averages; Europe's climate was still warmer than it is now. These conditions favored the spread of broad-leaved plants, which are characteristic of temperate and cold climates today.

The climate of the American continent during this era was similar to that of Europe; it was considerably warmer than it is today. The flora in relatively hot climates was composed largely of palms, while in the cold and temperate zones the dominant trees were birches, oaks, and maples, as shown in the illustration

THE OLIGO SEA—During the Oligocene, the sea wa both flora and fauna, but unfortunately ch has left no collection of fossils and complete as some found from periods. However, deposits in France Italian Apennines contain a great va wer fossils. The illustration of a typical southern European Oligocene sea shows small organisms that lived on the sandy seabeds some tens of millions of years ago. Because the period of time involved was brief, geologically speaking, the sand of the seabed has solidified very little, forming weak and incohesive rocks. The Italian Apennines are composed almost entirely of such rocks; modern road builders face high risk of landslides in these areas.

Among the protozoa illustrated here are numerous examples of *Nummulites*, while the mollusks include *Natica crassatina* and *Pecten*.



FAUNA OF THE OLIGOCENE | animals ... mid-Ter... ry times

The Oligocene epoch, a relatively brief span of approximately 15 million years, produced an amazing variety of totally new forms of higher fauna, of which the mammals were representative. Most of the once-new forms are now extinct, while those that have survived have changed greatly in size and shape. Some animals that were small in Oligocene times are now large; others, once larger, diminished in size and became extinct. In the history of life on the Earth, with a few notable exceptions, gigantism ordinarily has been a prelude to extinction.

The evolution of the higher fauna took place so quickly during the Oligocene that very few animals of the previous epoch remained unchanged. In the normal course of evolution, new forms derived from older forms, and these new forms continued to evolve and diversify. The ungulates, or hoofed mammals, exemplified the animals that underwent rapid evolution during the Oligocene epoch. Other mammals adapted themselves to the new situations that arose in the course of time. Among them were the cetaceans (whales, dolphins, porpoises), the chiropterans (bats), and the higher primates (monkeys and apes).

The northern continents were the major centers of mammalian evolution. The commonest fossils of the North American Oligocene epoch are the oreodonts—the most prominent of the artiodactyls (hoofed mammals having an even number of functional toes on each hoof) that were destined for extinction. Oreodonts were piglike, cud-chewing mammals. They have not been found elsewhere.

South America's isolation at the time was responsible for the development there of peculiar types of ungulates, some of which resembled horses, camels, and elephants, and some not readily comparable to animals of other continents. All became extinct in the Pleistocene epoch with the invasion of South America by predators and other herbivores.

1a

EVOLUTION DURING THE OLIGOCENE — Of the significant evolutionary events of the Oligocene, the most important were the adaptation and dispersion or distribution of the mammals.

The entelodonts and anthracotheres, primitive piglike animals, evolved with tremendous speed during the Oligocene, after having emerged during the preceding epoch. These animals became highly specialized and widely distributed during the Oligocene, but they became extinct after a relatively short time. Evidence of their rapid evolution has been found in the jawbones of various species, which succeeded one another very quickly.

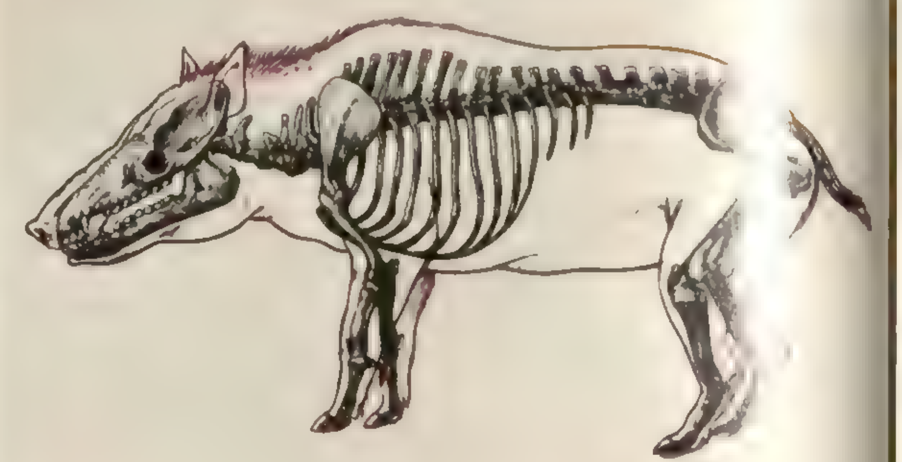
Archaeoterium mortoni (illustration 1a), of the family Entelodontidae, had remarkably well-developed incisors and canines; its skull attained a length of almost 1 m (about 3 ft), but the cranial cavity was of absolutely minimal size, indicating a very tiny brain.

In the jawbone of *Anthracokeryx* (illustration 1b), a member of the family Anthracotheridae, the teeth were only partly typical of a herbivore; the large fangs (canines) suggest a resemblance to the swine. The teeth of *Anthracotherium magnum* (illustration 1c) were more characteristic of a normal herbivore.

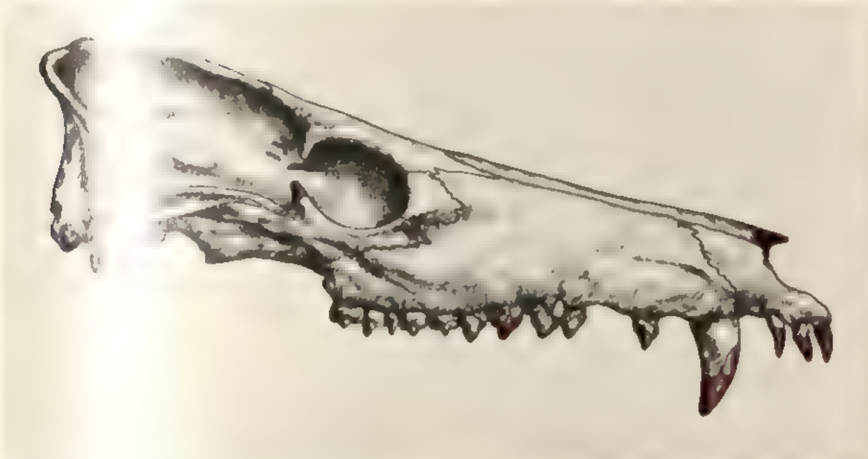
Anthracotherium scotti (illustration 1d) had an archaic appearance, with a dorsal crest that became less prominent in the more highly evolved types. Its skull was quite large, and its teeth were quite unlike those of a herbivore.

The Oligocene witnessed a great number of migrations of animals, particularly mammals. By comparing the fossilized skeletons of different species found in various parts of the world, paleontologists can reconstruct the story of their travels. Three factors were particularly important in animal migrations. During the Oligocene, land passages still existed between the continents; therefore, animals could cross from one continent to another in places that are presently under the sea. The fact that the Temperate Zone extended far to the north was another factor favoring animal migrations;

1c



1b



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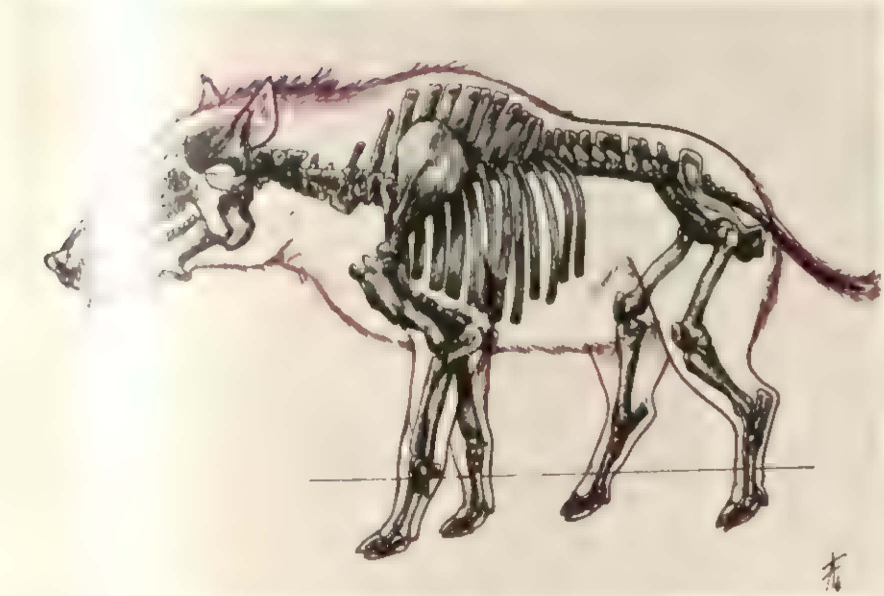


with relatively mild conditions existing over a large area, animals could move easily from one latitude to another whenever natural barriers blocked off the direct route. For example, animals could pass from one tropical area to another by way of a northerly passage without suffering any great hardship produced by climatic change. The third significant factor favoring migration was the warm-bloodedness of mammals; these animals were able to survive and function well despite any sudden changes in the environmental temperature.

By comparison, migrations of reptiles were much more restricted than those of the mammals, even over long periods of time. Their migrations along the coast of the Tethys (a warm sea that extended from the present Mediterranean to eastern Asia) were much less extensive and less important than those of the mammals. As cold-blooded animals, reptiles often found themselves faced with insurmountable climatic barriers.

THE FIRST OF THE SWINE—The earliest representatives of the swine (superfamily Suoidea) appeared during the Oligocene. These illustrations show the structure of the skull and teeth of two types: *Palaeochoerus* (Illustration 2a), the archetype of the pig family (Suidae), and *Perchoerus* (Illustration 2b), the first of the peccary family (Tayassuidae). In these primitive swine, the upper canines were still straight; modern swine have very specialized upper canines that curve outward and forward to form tusks. These teeth in present-day swine function both in rooting for food and occasionally in defense.

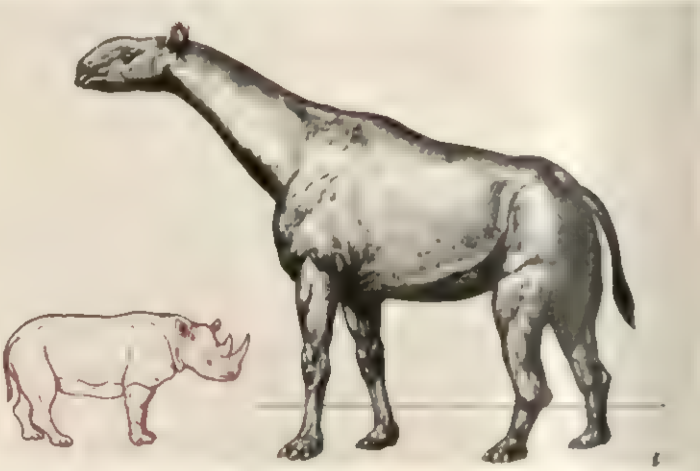
2

a

b

3b

3c



GIANTS AND DWARFS—A number of giant and dwarf animals lived during the Oligocene epoch. Many present-day mammals have descended from Tertiary forms that were characterized by enormous size and forbidding armament. These animals, in turn, had descended from earlier dwarf forms whose miniature size was all the more remarkable in view of the bulk which their descendants achieved.

Arsinotherium (Illustration 3a) had an enormously strong skeleton and a mighty skull topped with two great horns. The legs were extremely powerful, and the thorax was of large capacity. The fossilized remains of this huge mammal were found on the surface of Oligocene deposits in Egypt.

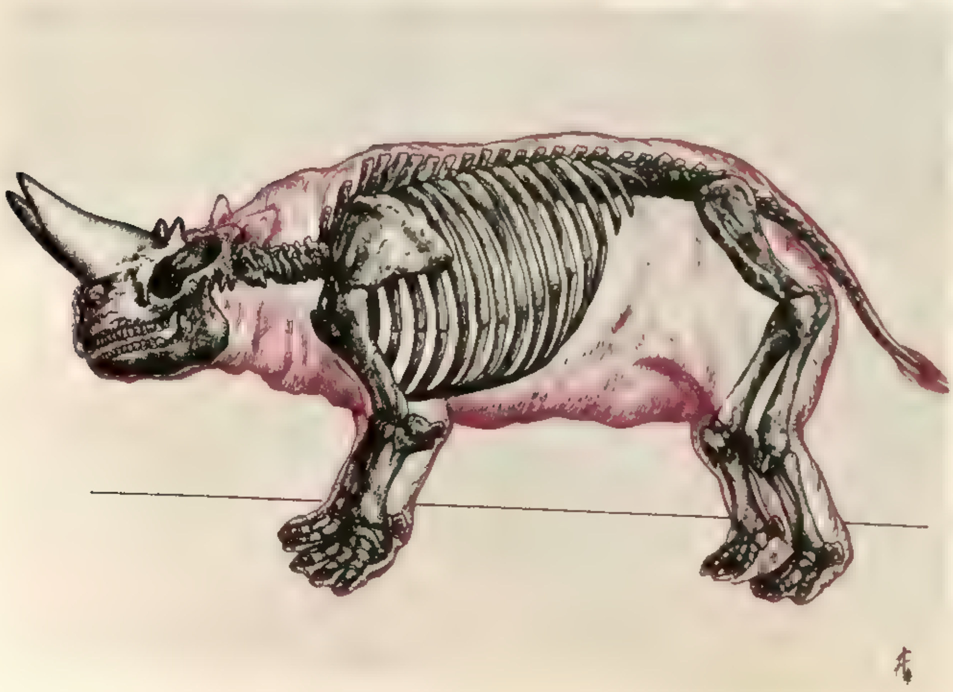
The great weight of *Brontotherium platyceras* (Illustration 3b) was supported by sturdy legs and feet similar to those of modern elephants. This animal descended from a diminutive Eocene animal (shown in red), which had lived 20 million years earlier.

The rhinoceros family is still in existence today, but its members are being exterminated so rapidly that they may soon become extinct. The modern rhinoceroses retain the primitive appearance of their ancestors; indeed, in many ways they resemble certain reptiles of the Mesozoic era.

One of the earliest rhinocerotids was *Hyracodon,* a very small, agile, hornless animal, whose habits paralleled those of horses. Its teeth were those of a herbivore, and its three-toed feet were lightly built. This animal became extinct at the end of the Oligocene.

Baluchitherium (Illustration 3c), whose fossil remains have been found in Mongolia, was another primitive rhinoceros—but a huge one. For purposes of comparison, a modern African rhinoceros is shown (in red) beside it. *Baluchitherium* was a colossal beast, the largest terrestrial mammal of all time; with its head slightly raised, *Baluchitherium* easily topped 6 m (about 19 ft) in height. This hornless, herbivorous animal retained its eating habits even in later epochs when its size was more modest. Its feet were rather like an elephant's, capable of bearing great weight. The lips were prehensile, but showed no evidence of becoming or even resembling a trunk.

3a



THE MIOCENE EPOCH | geography, climate, and life

← **A SIGN OF MODERN TIMES** — No plant has more right to be called a sign or symbol of modern times than does the poplar. Distributed in all temperate and cool climates where sufficient moisture is available, this fast-growing tree is of great commercial value. The many varieties of poplar found on the Earth today are distinguished by their different leaf forms and different general shapes.

The leaf illustrated comes from a fossil deposit in Baden, a region in southwestern Germany that in Miocene times was a low-plains area dotted with lakes. Poplars grew along the shores of these lakes. The exceptionally well-preserved leaf still shows the ramifications of the veins or nerves in minute detail. On the basis of its color, it might be mistaken for a leaf that has just fallen from a tree in autumn. Actually, the appearance is due to carbonic residues in the material of the vein or nerve system.

The rock in which this leaf is preserved was formed by the consolidation of very fine sediments (mud) of the type deposited at the bottom of a still lake. This particular specimen also contains fragmentary remains of other plant bodies.

The fourth epoch of the Tertiary period, known as the Miocene, began about 25 million years ago and lasted for about 14 million years. The biological forms inhabiting the Earth during this epoch were more modern in appearance than those of preceding epochs. The marine faunal provinces that characterize the present-day world began during the Miocene. Both on land and in the sea, mammals continued to evolve with great rapidity.

Geological events of th[…] Miocene can be related in great detail, […]incipally because they occurred in t[…]elatively recent past. Because of the[…]cent formation, Miocene deposits […] found near the surface of the Eart[…]rust, where they are readily accessi[…]o study. In part, the recency and […]ssibility of these deposits have led […]ome confusion over the subdivisio[…]e Miocene; as a result, different […]cations are used in different parts […] world.

Among the importan[…]genic phenomena of the Miocene […]crustal deformations in the Alps […]rtain other

mountainous regions, and a rejuvenating uplift of the Sierra Nevada and Rocky Mountain ranges. Intensive volcanic activity occurred in the vicinity of the Columbia River and in central and southern California. Some mountain-building activity occurred in southern California early in the Miocene, while the Cascade Mountains of the Pacific Northwest began to rise in the epoch. Much of the orogenic and volcanic activity begun during the Miocene continued into the Pliocene, and some of it persisted even into Pleistocene times.

The Miocene was also characterized by a complicated history of marine transgressions and regressions. The continental blocks were quite similar to those of the present day, differing only in certain details.

THE FAUNA

Biologically as well as geologically, the Miocene was marked by outstanding developments. Fossils of the lower marine fauna have been perfectly preserved, thereby enabling paleontologists to distinguish clearly the various levels of deposits. Fossils of the higher species also furnish evidence that permits reconstruction of such events as the specialization of life-forms in basins that at some time were isolated from the rest of the sea.

GEOGRAPHY OF THE MIOCENE—Geographically, the Miocene Earth differs from the present-day Earth in a few details only; the differences stem principally from the fact that the sea level was different in areas that had always been epicontinental, for the advance or retreat of the sea can change the entire shape of a continent. Allowing for these minor differences, Australia in Miocene times appeared much as it does today, and the same can be said of the Far East as a whole. The valleys of the Indus and the Ganges were actually two deep-sea inlets to the north of which rose the heights of the Himalayas. The Mediterranean was joined to the Indian Ocean by a narrow channel that in effect was a westward continuation of the Persian Gulf. The Alps and the Apennines were surrounded by waters that covered the areas of Germany, Denmark, the Netherlands, and adjacent countries.

North America had more or less its present shape, except for the tongue of land that today forms the Florida Peninsula. The orogenesis of the Rocky Mountains was nearly completed, and the Pacific coast was characterized by a notable chain of volcanoes, most of which have subsequently disappeared under the sea. Central America and the islands of the Caribbean were somewhat different from what they are today. South America, on the other hand, was practically the same in Miocene times as it is today—with the exception of the great gulf that surrounded the mouth of La Plata River. Ten million years passed before this gulf was filled with the sediments carried by the river.

The outline of Africa was practically complete, except for a few minor details, such as the formation of the Red Sea.

The Miocene might justifiably be called the epoch of the mammals, for during this interval of Earth history mammalian forms became extremely diversified and widely distributed. The epoch was marked by great migrations of these animals from one part of the Earth to another. Nearly all contemporary groups were represented, and they differed only slightly from present-day mammals. Among the ungulates or hoofed mammals present during the Miocene were rhinoceroses, horses, hippopotamuses, giraffes, antelopes, cattle, and swine.

Among the carnivores, the huge beardogs were conspicuous. Mastodonts spread for the first time into North America. There, as grasslands spread more widely, browsers were soon surpassed by grazing mammals. The distinctive South American mammals still were isolated on their insular continent as were the marsupials and monotremes of Australia.

THE CLIMATE

The climate of the Miocene can be described with considerable accuracy. Plant fossils from this epoch indicate that the climate was relatively cooler than it had been during the Eocene; the gradual decline in temperature continued throughout the subsequent epoch, the Pliocene, and culminated in the great glacial ages of the Pleistocene. During the Miocene, however, climatic changes were not yet pronounced. The boundaries of the tropical zone extended into relatively high latitudes in both hemispheres.

Yet, nipa palms no longer grew on the site of modern London as they did during the earlier Eocene epoch. The extensive Eocene tropics had already shrunken toward the equator. Vegetation, responding to climatic change through the Cenozoic period, shifted equatorward along the north-south trending mountain ranges that bordered the Pacific except where east-west trending beaches interfered, as in Malaysia and the Caribbean. Where mountains run east-west through the old world, however, a Miocene Mediterranean flora was ancestral to the modern flora upon which human agricultural civilizations first grew.

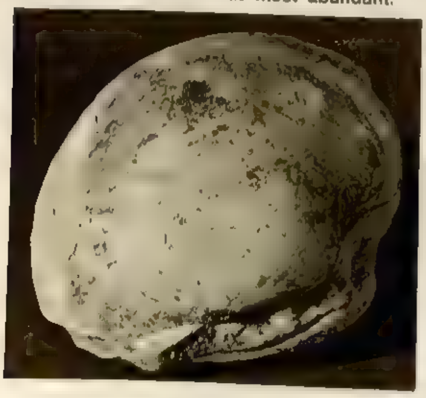
THE SEAS OF THE MIOCENE | further evolution of mar[illegible]ne fauna

The Miocene epoch was distinguished not only by great evolutionary events on land, but also by continued developments in the sea. From the paleontological point of view, the worldwide evolution and distribution of foraminifers, mollusks, and echinoderms were especially significant. Of ancient origins, all these animals had already diversified into a great profusion of species. Speciation was so great, in fact, that paleontologists have been able to trace the evolutionary variations of the fossil associations—that is, the complex of species found in different combinations in different strata.

Among the echinoderms, *Clypeaster*, *Scutella*, and, especially in the sandy facies, *Echinolampas* were particularly widespread. Among the mollusks, *Pettinida* was typical of basins with sandy bottoms, while *Cardiida* and *Congeria* were characteristic of the basins of lakes and lagoons. Remains of organisms such as these are important as guide fossils, enabling paleontologists to subdivide the Miocene into ages and to correlate the deposits found in different parts of the world.

The cetaceans (whales, dolphins, and porpoises), which first appeared in the seas during the Eocene epoch, took on more modern forms and populated Miocene waters in large numbers. Sirenians (sea cows), which occupied the shallow waters near shores, also became modernized. Moreover, the Miocene witnessed the appearance of the pinnipeds (seals and sea lions), mammals that were well adapted to life in the water, but that spent some time on dry land.

A MIOCENE SYMBOL—The bivalve mollusk *Venus* might well serve as a symbol of the fossilization of the lower animals of the Tertiary and Quaternary periods. It is still very common today. This specimen lived during the time when *Venus* was most abundant.



SEDIMENTATION DURING THE MIOCENE

Scientists normally distinguish between waters covering the continental shelves and the waters of the deep seas, because different kinds of organisms populate these environments. They also distinguish between the large oceanic basins and the geosynclinal seas. The latter, often with depths in excess of 1,000 m (about 3,200 ft), were produced by folding of the Earth's crust. The sedimentation of the ocean floors has been of little stratigraphic interest, for these areas have always been covered with very deep water. Sedimentation of the geosynclines, however, has been of great interest because it often occurred rapidly. The intensity of this sedimentation is exemplified by rocks of marine origin formed in the geosyncline of the Alps and subsequently raised to form mountains.

Sediments in epicontinental seas or lagoons furnish paleontologists with vast quantities of materials for study. During the Miocene, in an area east of the Mediterranean Basin, numerous bodies of water underwent a sequence of changes—from deep seas to epicontinental seas, then to lagoons, lakes, salt lakes, and finally to saline deposits. Biologically, these changes are of interest because they imply progressive changes of temperature and salinity. A deep sea always contains some cold water, usually at great depths, and certain kinds of animals may live in these cold-water regions. Such a sea also has a low percentage of salts, generally equal to the average salinity of all the world's seas. As the se[illegible]adually becomes shallower, the te[illegible]ature of the water tends to rise—pro[illegible]g that solar radiation is not diminish[illegible]At the same time, the sea becomes sal[illegible]nd murkier, because the bottom is n[illegible] the surface and currents stir up and[illegible]tribute mud from the bottom. The sp[illegible] of sedimentation, therefore, increa[illegible] so that the thickness of the deposi[illegible] greater in comparison with the ti[illegible]t has taken for them to accumulate.

When the water is v[illegible]allow, conditions change even mo[illegible]uickly. The level of salinity increas[illegible]rapidly, and the temperature of th[illegible]water varies widely, depending on the[illegible]ount of solar energy received at differ[illegible] times of the year. The waters of a l[illegible]n no longer serve as a stabilizer of[illegible]erature, as do the waters of a sea[illegible]goon, therefore, is subject to clima[illegible]riations imposed by factors of mo[illegible]note origin.

SEA MOVEMENTS IN THE MIOCENE

Two widespread expa[illegible]s of the sea following the Oligocene [illegible] emergence were interrupted during[illegible]niddle Miocene interim by local[illegible] mountain-building and shifting of[illegible] shelf seas. Late Miocene time was f[illegible]wed by another interval of crustal[illegible]lift and regression of the seas. Alth[illegible]gh a barrier apparently cut it off from the North Sea, the Miocene Atlantic Ocean was connected with the Mediterranean Sea by way of Andalusian and northwest African straits. A late Miocene sea extended eastward over Hungary, southern Russia, and Turkistan, eventually changing into a saline inland sea of which the Aral, Caspian, and Black seas are shrunken relics. The Tethys Sea was finally sealed off by middle Miocene times. Eastward, beyond a nonmarine upper Burma spread an Indo-Pacific Ocean. In the western hemisphere, the Americas remained largely above the seas.

THE MIOCEN[illegible]—Designed to provide a comprehensiv[illegible]ure of the sea during the Miocene epo[illegible]illustration includes flora and fauna fr[illegible]egions that actually were great distanc[illegible]art. It shows a relatively deep sea pop[illegible] by fish that were not much different from[illegible] existing at the start of the Tertiary p[illegible] That fish existed in abundance is indic[illegible]by the presence of a great number of pr[illegible]

The seas [illegible] Miocene epoch were not cold, and m[illegible]ropical plants grew along their coasts. T[illegible]rm climate extended northward as far a[illegible]ndinavia, where today only poplars and b[illegible] grow.

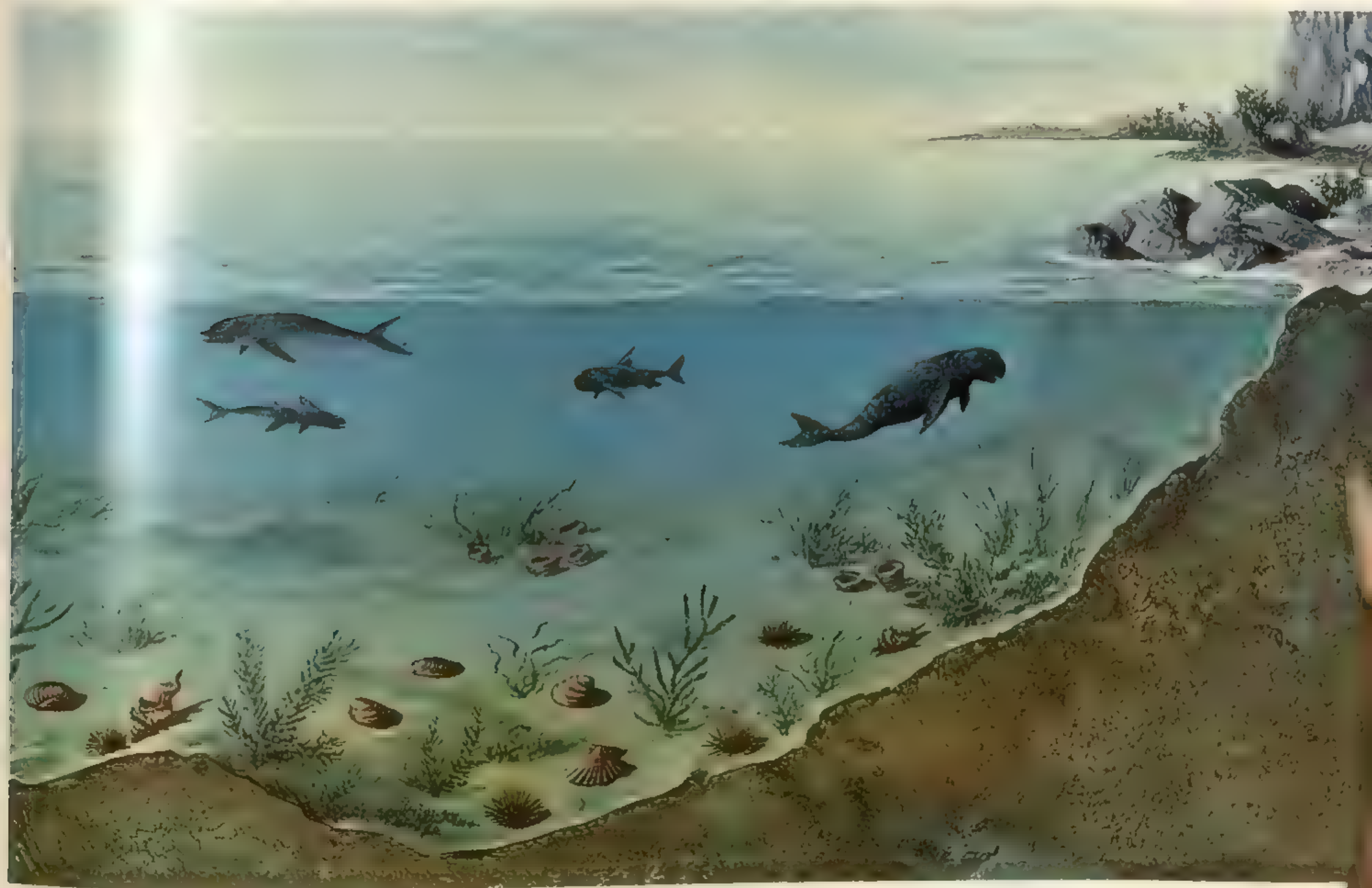
The lower [illegible]tic fauna included some kinds of mol[illegible] that are still living today, although som[illegible]ve changed in size and others are ra[illegible]*nus*, *Pecten*, and *Crassostrea* are exam[illegible] of mollusks that have survived to the [illegible]ent day. Very large specimens of the [illegible] have been discovered in Pliocene deposits; because they fossilized quite recently, these specimens retain a nacreous sheen.

Echinolampas was an echinoderm common in Miocene times; it existed for such a limited time that it is useful as a guide fossil. The beds of Miocene seas no longer harbored nummulites, which had been abundant during previous epochs. These large foraminifers were replaced by orbitoids such as *Lepidocyclina* and *Miogypsina*, which, in turn, disappeared suddenly after the Miocene epoch.

Many representatives of the order Sirenia (sea cows) populated the seas along the palm-fringed coasts; these animals fed on aquatic plants. Of the order Cetacea, both toothed whales (odontocetes) and baleen or whalebone whales (mysticetes) were present in great numbers, especially in the open sea.

An exceedingly large number of fossil remains accumulated in the deeper parts of Miocene lagoons and shallow seas, because life was very plentiful in these bodies of water. In these places a process of fermentation produced sulfuric eruptions. The lagoons then underwent a change of the utmost biological interest.

When a lagoon was formed by being cut off from the sea, the salinity of the lagoonal waters sometimes increased rapidly as a result of evaporation (the proportion of salt to water increased). On occasion the lagoon was then invaded by fresh waters from the surrounding land, and the proportion of salt to water changed again. In this case, sea-dwelling species first had to adapt to conditions of increased salinity in order to survive; later they had to adapt to conditions of greatly decreased salinity. The seas and lagoons that occupied the area of the present-day Black Sea during Miocene times experienced just such changes as have been described. In fact, life in the modern Black Sea is still faced with similar changes in environment.



FORESTS OF THE TERTIARY | characteristic trees of the period

Superb examples of fossilized leaves are fairly common in some of the sedimentary deposits of the Tertiary period, especially in the more recent deposits. One feature of these deposits is that they are not tightly bound. Sandstones and conglomerates flake or break rather easily, often splitting with a single blow of a geologist's hammer. Striking the rock tends to break it along planes that often contain fossils; in fact, the presence of fossils often weakens the rock so that it breaks more readily than a rock without fossils.

Fossils are found where one phase of sedimentation stopped and another phase began; this means that fossils are found between two layers of rocks with different grains or degrees of compactness. Striking a sedimentary rock is likely to cause it to break along the plane separating the two layers and is likely to reveal fossils if any exist.

Plant fossils constitute a special case, for they are very delicate, and even the slightest alteration in the rock eradicates all signs of them. Mention has been made elsewhere of the manner in which rocks change as a result of movements in the Earth's crust. However, because these movements in the remotest eras cannot be traced accurately, these events have always been discussed in very general terms. For example, the Hercynian orogenesis left traces in the r s that today comprise the Alps, but it preceded or followed the orogen s unknown. On the other hand, the of the sedimentation of the Trias pine Sea is quite well known; this the process by which the rocks no uprising the Dolomites were origina med. These rocks remained under l or under the sea for tens of mil'i of years before being raised up only the shells of fossilized an relatively well preserved in the s phase of sedimentation was the wed by the various phases of the orogenesis which little by little the Alpine heights. The deposits lasse, found

PAGE FROM A HERBARIUM — This illustration could represent a page from a herbarium of the Miocene and Pliocene epochs, as it shows a few of the leaves of typical plants from those epochs. In effect, this is a collection of plants most characteristic of the so-called modern flora.

Torreya nucifera (illustration 1a), a gymnosperm of the order Ta was a typical Miocene plant that bore a resemblance to the present-day Engl (*Taxus baccata*). *Punica planchoni* on 1b) was a Pliocene plant with Mioc estors

The oak, *Quercus rob* ation 1d) has remained unchanged from e times down to the present day; an ak, *Quercus praeilex* (Illustration 1e) Miocene, appeared earlier and has d practically unchanged into modern

Very often species that t recent bear names indicating that they en fossilized by petrifaction. *Quercia* the Quaternary, for example, was fo in travertine

Populus latior (Illustrat was a poplar that grew on the shores s during the Miocene epoch. *Salisbur* *tordes* (Illustration 1g) was also a M plant, while *Sassafras ferretianum* (Il n 1h), spanning both the Miocene Pliocene, descended from species alr existence at the very beginning of the ry

Fagus pliocenia (Illustr 1i), the most recent species of Tertiary had leaves almost identical to those present-day *Fagus silvatica*.

Cercis virgiliana (Illustrat 1l) dates from the Miocene. Both *Acer p* *morphum pliocenium* (Illustration 1m) and *Acer laetum pliocenium* (Illustration 1c) were Pliocene trees that have played important roles right up until the Quaternary; indeed, in the fairly recent history of civilization, the pioneering routes traversing Canada and the northern United States passed through regions where maple trees flourished.

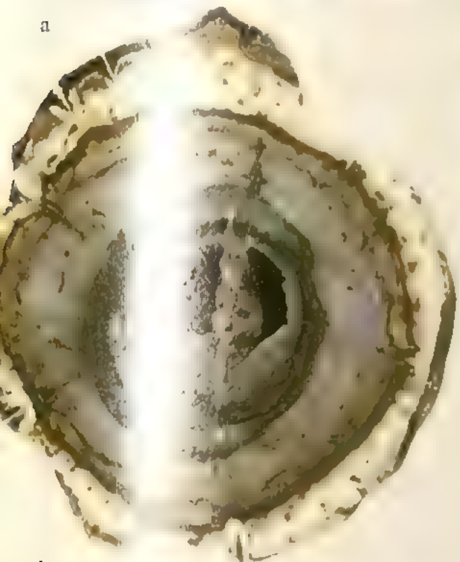
Tilia vindobonensis (Illustration 1n) was common during the Miocene in both Europe and North America; the species that preceded it were also characteristic of both regions.

From this brief survey, it is evident that the trees of the Pliocene epoch were really very much like those of today. Ten million years after all, are relatively nothing in the face of the slow evolution characteristic of the Plant Kingdom.

2

A LIVING … —The maidenhair tree. *Ginkgo bi*… truly be called a living fossil. It is… very ancient origins, far older than… trees of the Tertiary. Fossils, fully… on years older than the Eocene sp… section of petrified trunk) shown in I… 2a, have been discovered in Jurassic… The origins of this specimen can I… directly to the Cordaitales of the Pe… riod. After a long life in which it s… in remaining virtually unchanged, I… managed to withstand the shocks a… es of the Quaternary. Although in… to China, *Ginkgo biloba* today is… cessfully in temperate regions of… nd North America. Leaves of this livin… re shown in Illustration 2b.

a



b

3

a

b

MESSAGES FROM THE LIFE OF THE TERTIARY—During the Tertiary era the atmosphere was laden with pollen, even as it is today in the great forests of the world. When pollination occurs in these areas, clouds of pollen descend over great tracts of land. Lime pollen, a grain of which is shown in Illustration 3a, was already present in the atmosphere of the Tertiary forests, especially toward the end of the period. Illustration 3b shows a grain of pollen of *Manilkara longipollinia*, a plant typical of the Oligocene epoch.

not only to the south of the Alps, but also to the north, on the Swiss side, were formed by an orogenesis that proceeded by fits and starts; but the Tertiary deposits have undergone few changes. For example, those of the Alpine area have not been subjected to intense folding or to thermal changes, such as occur whenever the rocks are affected by an intrusion of magma.

Tertiary plant fossils, apart from being present in great numbers even in areas where vegetation was not particularly flourishing, are also well preserved. The most recent of them, dating from the Miocene and Pliocene, sometimes appear as though they were yesterday's foliage just covered with a layer of dry mud. Nevertheless, these plant remains have been imprisoned in rocks for millions, and in some cases for tens of millions, of years. For this reason, important changes may have occurred in the fossils themselves. One of the most typical changes involves the process of silicification. Some of the best examples of silicified (or petrified) tree trunks date from the Tertiary era.

Any outline of the complicated flora of the Tertiary must begin with the observation that it closely resembled present-day flora; only climatic differences have determined a distribution of plants different from that known today.

The climate of the Tertiary in most parts of the world was initially hot—practically tropical—but became colder during the later epochs. In any case, the climate was homogeneous, changing slowly and evenly. It was not variable in the sense that the climate of the Quaternary was variable, for the Quaternary was marked by alternating episodes of glaciation and interglacial warming.

THE MIGRATIONS OF THE MIOCENE EPOCH | the dispersal of certain species

The rocks of the Miocene epoch contain a wealth of detail for study by geologists and paleontologists. Fossils from earlier epochs and periods often allow only the compilation of incomplete lists of types of organisms. However, some Miocene deposits are veritable mines of fossils and information that enables scientists to reconstruct the various ecological environments in which animals lived.

The most important plants of the epoch are well known; therefore, scientists can locate the forests of the Miocene and identify the climates. The lesser plants, which indicate locations of open grasslands, are also known; in certain instances, scientists are able to identify the particular kinds of grasses that grew in different areas.

Considered together, these elements of detailed knowledge indicate a biological evolution that had become very rapid indeed. The explosiveness of the evolution probably resulted from the fact that it involved species that were already highly evolved, species with features and characteristics so delicate or so specialized that they were affected by the slightest changes in the environments to which they had become adapted.

EVENTS OF LASTING IMPORTANCE

One of the most important changes that occurred during the Miocene epoch was the isolation of the Euxine Sea, a body of water extending from the eastern end of the recently upcast Alps to the east of the present Caspian Basin. It may have been connected with the eastern Mediterranean, which in Miocene times had an outline similar to its present outline. The Euxine Sea was connected to the Indian Ocean by a channel running through the Middle East and the Persian Gulf. This sea became a shallow lagoon in which quick and intense changes in salinity provoked marked environmental adaptations among the mollusks and other lower animals living in it.

The Miocene also witnessed a succes-

THE STORY OF MIOCENE MIGRATIONS— Tracing the migrations of higher animals during the Miocene epochs depends on a knowledge of its fossils and the exactitude with which the stratigraphy of the epoch can be determined. For example, if the fossils of a given species are found in Lower Miocene deposits in America only, and in Upper Miocene deposits in Europe, with perhaps a few specimens in Middle Miocene deposits in Asia, emigration from America to Europe by way of Asia is indicated. Only with a pattern as clear as this can scientists trace an actual migration. Fortunately, detailed reconstruction of migrations during the Miocene is possible, because the subdivisions of the epoch are quite certain, albeit complicated. Moreover, fossils exist in such great numbers that, if certain species are not found in a given stratum, it is safe to say that they did not live at the time corresponding to that stratum.

This map of the Miocene continents shows the intercontinental migrations of certain groups of mammals.

Members of the genus *Hipparion* were three-toed horses descended from *Merychippus*, but were not ancestral to modern horses. In the span of about 10 million years, these animals migrated a distance of about 50,000 km (about 31,000 mi). This means that their rate of travel was about 5 m (about 16 ft) per year or about 14 mm (about 0.55 in.) per day. Even if the *Hipparion* migration had been completed in a million years, the daily rate of movement would have been only 137 mm (about 5 in.). Actually, migrations consisted of a series of spasmodic movements in a certain direction; the movements were motivated or dictated chiefly by the need for food or the need to escape the pressures of overpopulation. Mass movements were facilitated by the prevalence of warm and sufficiently damp climatic conditions. Moisture was an important factor, for without enough precipitation, vegetation would have been insufficient for feeding these animals.

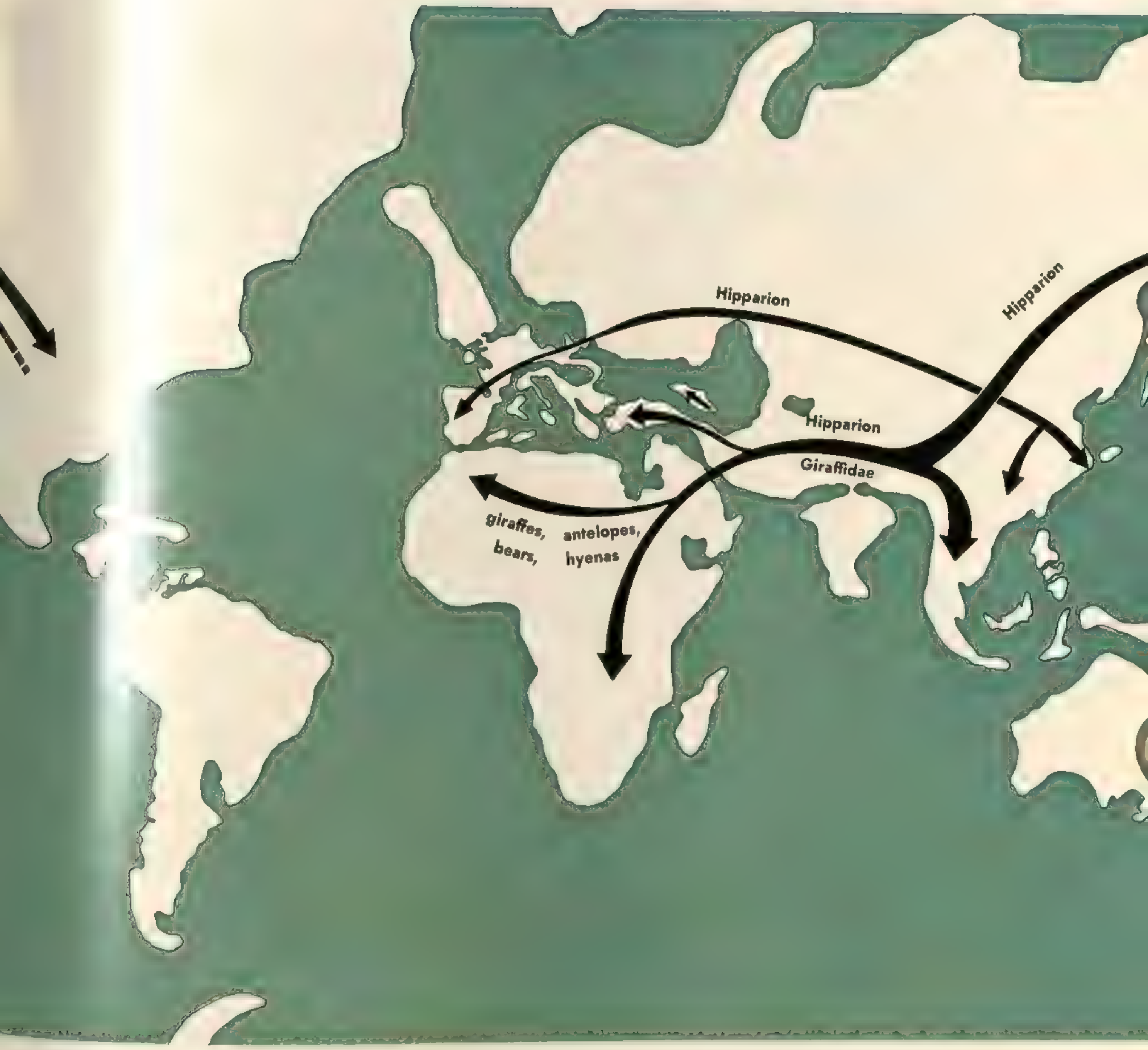
Hipparion supposedly began its migration in Nebraska, crossed the Bering Strait (then a broad strip of land above the level of the sea), and spread through Asia toward the south, crossing the narrow strip between the Himalayan geosyncline and the recently uplifted Himalayan range. Some members of the genus reached Europe, while others made their way to North Africa. Antelopes, bears, and hyenas followed the same route from Asia to Africa.

The Bering Strait, which served as *Hipparion's* passage to Asia, also served as a bridge for the rapidly developing proboscideans (elephants), which migrated in the opposite direction.

South America and Australia played no part in the Miocene migrations because they were separated from the other continental masses by extensive bodies of water. Asia, Europe, and Africa, however, witnessed another interesting migration, that of the giraffes. These animals first appeared in two fairly small regions: one corresponding roughly to present-day Mongolia; the other, the Ganges Basin. The

giraffes later spread over at least a quarter of the Earth's dry land.

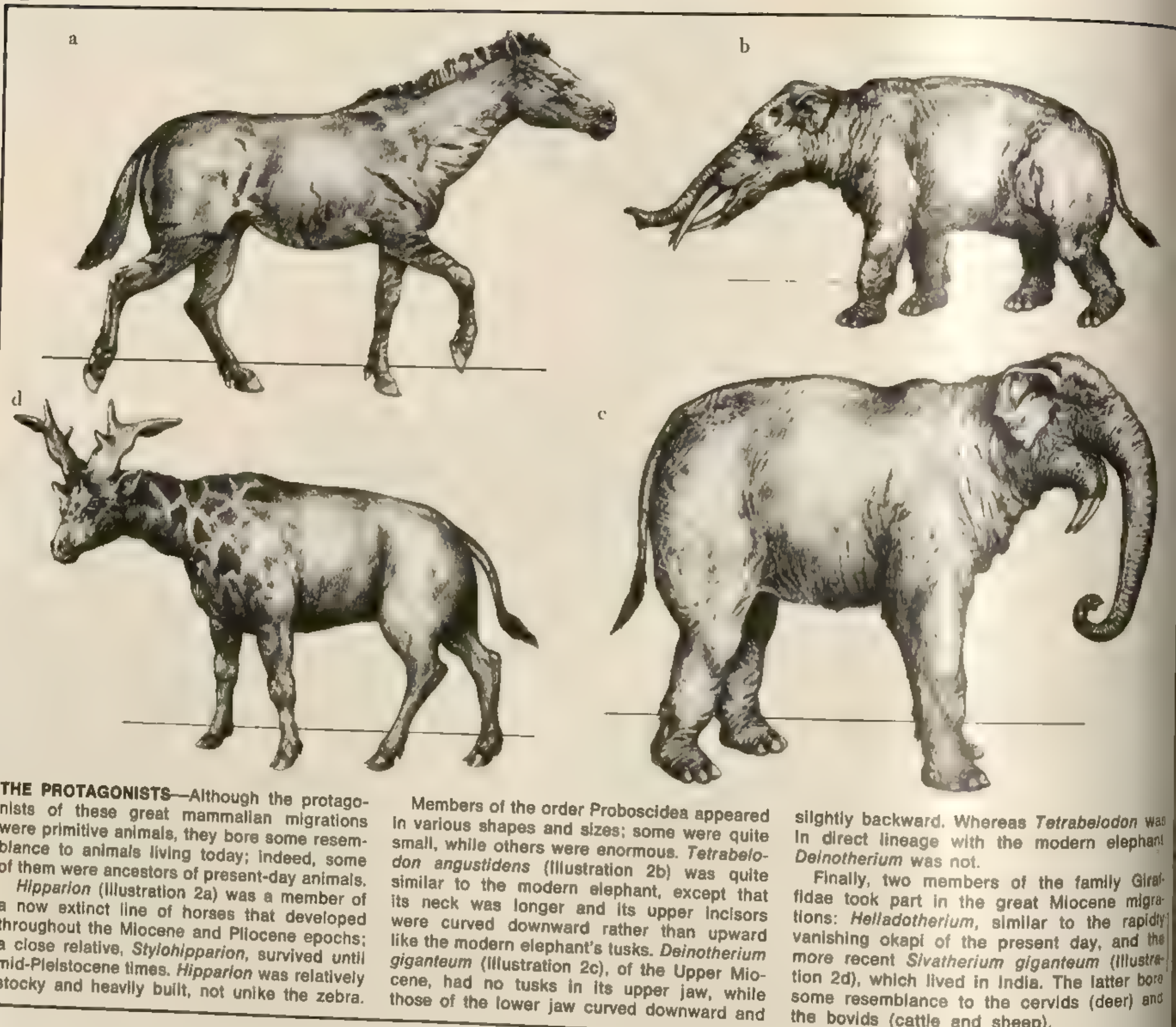
Giraffes appeared during the Middle Miocene, and by the end of the Upper Miocene the more primitive types had spread through central and southern Asia, Europe, and North



Africa. All this took place in the course of a mere 3 or 4 million years. Primarily because of climatic changes during the Pliocene, giraffes disappeared from Europe and took refuge in North Africa. However, they continued to inhabit almost the whole of that area of Asia to which they had moved during the Upper Miocene, and they also invaded southern India and Arabia.

During the Quaternary, a conspicuous change occurred in the distribution of the giraffes. These animals occupied all of Africa, but abandoned the parts of Asia where they had originated. More recently, giraffes disappeared altogether from Asia and the Middle East; they now are found only in tropical Africa, excluding the arid regions.

2



THE PROTAGONISTS—Although the protagonists of these great mammalian migrations were primitive animals, they bore some resemblance to animals living today; indeed, some of them were ancestors of present-day animals.

Hipparion (Illustration 2a) was a member of a now extinct line of horses that developed throughout the Miocene and Pliocene epochs; a close relative, *Stylohipparion*, survived until mid-Pleistocene times. *Hipparion* was relatively stocky and heavily built, not unlike the zebra.

Members of the order Proboscidea appeared in various shapes and sizes; some were quite small, while others were enormous. *Tetrabelodon angustidens* (Illustration 2b) was quite similar to the modern elephant, except that its neck was longer and its upper incisors were curved downward rather than upward like the modern elephant's tusks. *Deinotherium giganteum* (Illustration 2c), of the Upper Miocene, had no tusks in its upper jaw, while those of the lower jaw curved downward and slightly backward. Whereas *Tetrabelodon* was in direct lineage with the modern elephant *Deinotherium* was not.

Finally, two members of the family Giraffidae took part in the great Miocene migrations: *Helladotherium*, similar to the rapidly vanishing okapi of the present day, and the more recent *Sivatherium giganteum* (Illustration 2d), which lived in India. The latter bore some resemblance to the cervids (deer) and the bovids (cattle and sheep).

sion of great migrations of mammals across the continents. Some of these migrations took primitive horses from America to Asia, and thence to Europe and Africa.

Monkeys were widely distributed during the Miocene, and new species appeared. Many types of birds were also widely distributed; these animals possessed exceptional flying ability, rivaled only by species of the present day. Certain huge, flightless birds of the Miocene epoch had skulls as large as the skulls of modern horses. Antelopes were already common, living in herds on European and American grasslands. Hippopotamuses, camels, sheep, goats, mouflon (wild sheep), and sabertooth cats were also plentiful. Given enough time, any species could crawl from one land mass to another as long as conditions were favorable for survival. Worldwide distribution of ancient groups may simply demonstrate that they had time to disperse. The wide range of amphibians and reptiles may be due to their geological age, while the youth of mammals as a group may account for their limited range. Paths for dispersal open to ancient groups were closed to later ones.

THE ORIGIN OF THE MAMMALS | and their early evolution

The first tr[illegible]mmals appeared on the Earth duri[illegible] Triassic period, and the first gr[illegible]velopment of these animals occurr[illegible]uring the Jurassic. Fossil remains [illegible]teeth and fragments of jawbones c[illegible]tute the principal evidence of t[illegible] animals thus far discovered; n[illegible]heless, the evidence is sufficient t[illegible]how that the primitive mammals [illegible] small and insignificant animals.

In all pr[illegible]bility, the mammals descended ph[illegible]netically from some reptile-mamma[illegible]of the Triassic period. These latt[illegible]nimals played a role of enormous i[illegible]rtance in the history of the verteb[illegible] because they comprised the basic t[illegible] of organism from which all the va[illegible] kinds of mammals were subsequen[illegible]erived.

During [illegible] Triassic period, a group of synapsi[illegible]iles evolved in a direction that prod[illegible] bone structure very similar to th[illegible]ssessed subsequently by mammals. [illegible]erefore, these sinapsids have bee[illegible]signated as reptile-mammals and [illegible] been classified as members of th[illegible]der Therapsida, suborder Ictidosau[illegible] From a number of points of view, t[illegible]ctidosaurs can be considered the li[illegible] between the reptiles and the more highly evolved reptiles.

The ictidosaurs possessed several mammalian skull features, including generally smaller bones than the reptiles and a large temporal aperture confluent with the orbit of the eye. However, because the quadrate and articular bones still existed—even though they were quite small and nonfunctional—these animals are generally classified as reptiles. In mammals, these bones have shifted to the region of the middle ear, and they have changed to such an extent that they function to transmit vibrations from the eardrum to the inner ear. Although the ictidosaurs were highly specialized animals, they have not been classified as mammals precisely because this bone transformation had not yet occurred.

The most highly evolved representatives of the suborder Ictidosauria were rodent-like reptiles belonging to the family Tritylodontidae; an example is *Tritylodon*, whose fossil remains have been found in Triassic deposits in South Africa, and *Bienotherium*, which was discovered in Asia. These animals were distinguished by a high sagittal crest on the skull and zygomatic arches to which the jaw muscles were attached. The teeth were greatly differentiated.

The differences between the ictidosaurs and the primitive mammals, therefore, were not great, but the latter did not evolve in a direct line from the former. The ictidosaurs were, in fact, so highly specialized that they could not have produced the progenitor of the mammals. The first mammal must have been an animal with very general characteristics; otherwise, the development of the particular specializations of the different mammals would have been impossible. In all likelihood, the mammals had a polyphyletic origin—that is, a number of different groups of reptile-mammals probably contributed to the makeup of their basic progenitor. Problems of phylogenesis notwithstanding, the fact remains that during the Jurassic period the mammals took shape and be-

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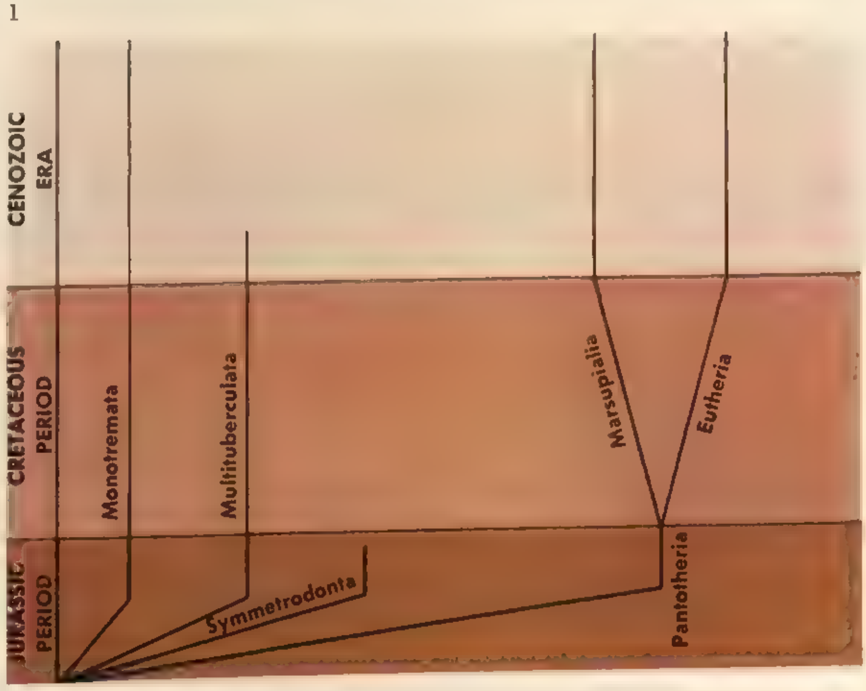


THE ORIGIN AND EVOLUTION OF THE EARLY MAMMALS—In all probability, the origins of the mammals must be sought among certain reptile-mammals of the Triassic period. The earliest representatives of the class Mammalia indeed appeared during the late Triassic. By early Jurassic times, four orders were definitely represented: the Triconodonta, Symmetrodonta, Multituberculata, and Pantotheria. The Marsupiala (pouched animals) and the Eutheria (placental mammals) are thought to have been derived from the pantotheres during the Cretaceous period; these groups underwent spectacular development during the Tertiary period of the Cenozoic era.

Another group, the Monotremata, is believed to have derived by direct evolution from the same Triassic ancestor as the other groups of mammals; however, the earliest monotreme fossils date from the Quaternary period of the Cenozoic era.

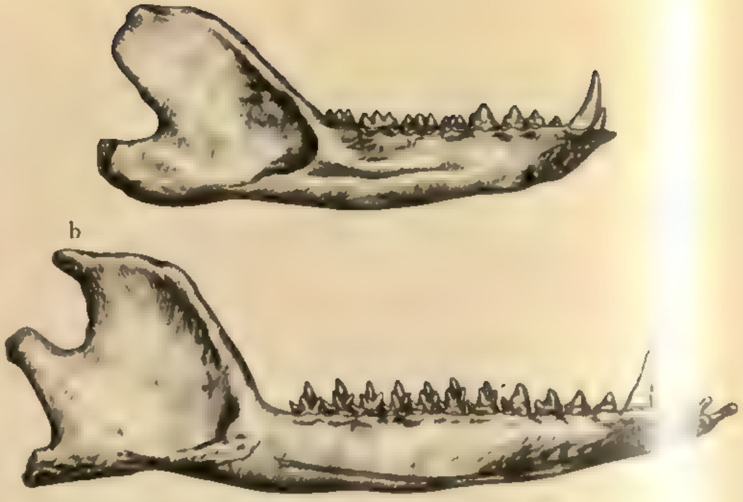
gan a process of evolution so rapid that it led to their becoming the absolute and unchallenged masters of the Earth.

The origin of mammals from reptiles occupied a period of about 40 million years. When the great complexity of the changes involved is realized, this is not surprising. Nearly every organ in the body was altered in structure.

Mammals possess a number of features that set them apart from other vertebrates. They are warm-blooded animals with a basically high metabolism; their bodies for the most part are covered with hair, which serves to conserve body heat. The young are born live (except in the case of the monotremes) and are nursed by the mother during the early stages of life.

3

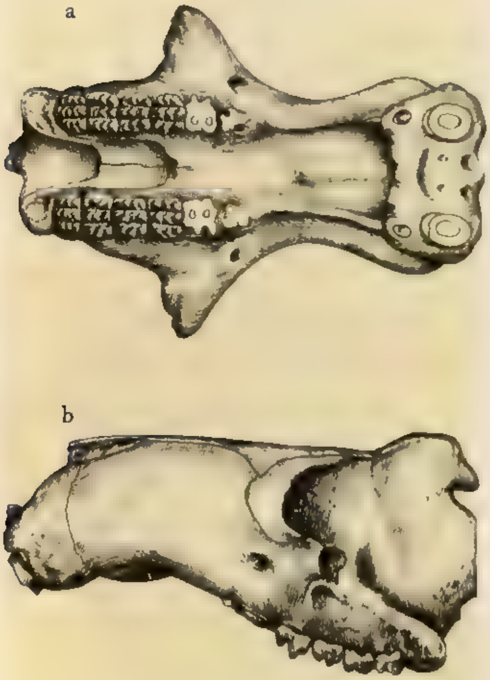
a



MAMMALS OF THE JURASSIC PERIOD—The only fossil remains of Jurassic mammals that have been discovered thus far are bits of skull, teeth, fragments of jaw, and pieces of palate. Illustration 3a is a reconstruction of the jawbone of *Triconodon*, in which the teeth were already differentiated into four incisors, one canine, and nine postcanines. Illustration 3b is a representation of the [illegible] of *Amphitherium*, a mammal commo[illegible]ng the Middle and Upper Jurassic; this [illegible]mal had four incisors, one canine, four pre[illegible]s, and seven molars. The teeth of primitiv[illegible]rsupials and of eutherians of the Cretac[illegible]period were arranged in much the sam[illegible]s the teeth of *Amphitherium*.

2

a



A REPTILE-MAMMAL—These illustrations are reconstructions of the skull of *Tritylodon*, one of the most highly evolved members of the suborder Ictidosauria. The palate (illustration 2a) clearly shows the differentiated teeth of this reptile-mammal; the pair of frontal incisors is clearly separated from the rows of lateral teeth, which are square in shape with longitudinal cusps. Illustration 2b shows the jaw from the side.

In all likelihood, these animals did not give rise to the entire line of mammals, although the differences between the reptile-mammals and the true, but primitive, mammals are not great.

All the aforementioned characteristics are important to the definition of the term *mammal*, but they are not demonstrable by the methods, or with the materials of, paleontology. In most cases all that remains of mammals of the past are skeletons or fragments of skeletons. Certain characteristics of these remains enable paleontologists to assign the animals to particular groups or categories. The previously mentioned transformation of the quadrate and articular bones into the hammer and anvil (auditory ossicles) is one characteristic of interest to paleontologists. Other significant osteological features include the presence of a double occipital condyle and a secondary palate separating the mouth from the nasal passage. In a mammal, the external nasal aperture is single; the joint between the jaw and the skull is formed by the squamosal and dentary bones; the skull has greater capacity than a reptile's skull; the teeth [illegible] differentiated; the ribs of the neck [illegible] fused with the vertebrae (the lumbar [illegible]ebrae bear no ribs); the bones of t[illegible] pelvis are fused; and finally, the bon[illegible] the digits of the forelimbs are red[illegible] to three phalanges, except for the first digit, which has two phalanges.

MAMMALS OF THE JURASSIC

Jurassic deposits have yielded numerous fossils that are attributed to as many as four different orders of mammals: Triconodonta, Symmetrodonta, Pantotheria, and Multituberculata.

The triconodonts of the Middle and Upper Jurassic have left remains of parts of the skull, the teeth, and fragments of the jaw and palate. *Triconodon* was a carnivorous animal, about the size of a cat, with a rather elongated jaw containing a fair number of differentiated teeth, including four incisors, a canine, and nine postcanines. The shearing teeth in

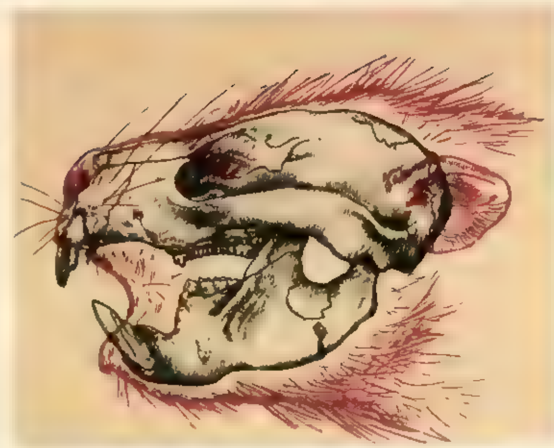
the cheeks [illegible] three cusps longitudinally arrang[illegible]
The symm[illegible]nts derived their name from the f[illegible]t each of their molars had three [illegible]rranged symmetrically in the form [illegible]iangle. Like the tricon-odonts, th[illegible]mals appeared in the Jurassic p[illegible]nd failed to survive into the Cr[illegible]us.
Far mor[illegible]rtant than the symmet-rodonts w[illegible] pantotheres, mammals that were [illegible] distributed during the Middle and [illegible]er Jurassic. The panto-theres wer[illegible]eterized by a long, nar-row jaw co[illegible]ng a broad row of lateral teeth. *Amp[illegible]rium*, for example, had four inciso[illegible] canine, four premolars, and seven [illegible]s: each molar had a tri-angular sh[illegible]ith a number of cusps. The arran[illegible]t of teeth in the panto-theres for[illegible]omplex cutting mecha-nism; the [illegible] of the first marsupials and placen[illegible]mmals in the Cretaceous period we[illegible]nged in a very similar manner. I[illegible] both the marsupials and the place[illegible]ammals are thought to have des[illegible] from the pantotheres of the Ju[illegible]eriod.
The m[illegible]rculates were herbivo-rous man[illegible]hose teeth had cusps ar-ranged lo[illegible]linally in rows. Each of these prin[illegible] mammals had a pair of large inc[illegible]oughly reminiscent of a modern r[illegible]in behavior also, a multi-tuberculat[illegible]ay have been similar to present-da[illegible]dents.

MAMMALS OF THE CRETACEOUS

Of the four orders of Jurassic mammals, only the multituberculates and some triconodonts survived into the Cretaceous period, but only the multituberculates survived into the Tertiary. These mammals specialized throughout the Cretaceous, and some species attained considerable size. *Taeniolabis*, for example, was about the size of a beaver and had a skull measuring over 20 cm (about 8 in.) in length.

The pantotheres probably disappeared during the Cretaceous, but not before giving rise to the metatherians (marsupials or pouched animals) and eutherians (placental animals). The most primitive marsupials, dating from the Upper Cretaceous, were rather similar to the modern opossum. Remains of early eutherians, dating from the same epoch, have been discovered in Mongolia; these primitive placental mammals were similar in shape to present-day insectivores. They occupied a minor niche among the hordes of reptiles that dominated the land during the late Mesozoic era. The eutherians lived on the ground or climbed in the lower strata of the vegetation. Like the opossum, these early forms were not highly specialized for any way of life that demanded much modification of the structural system inherited from the mammal-like reptiles.

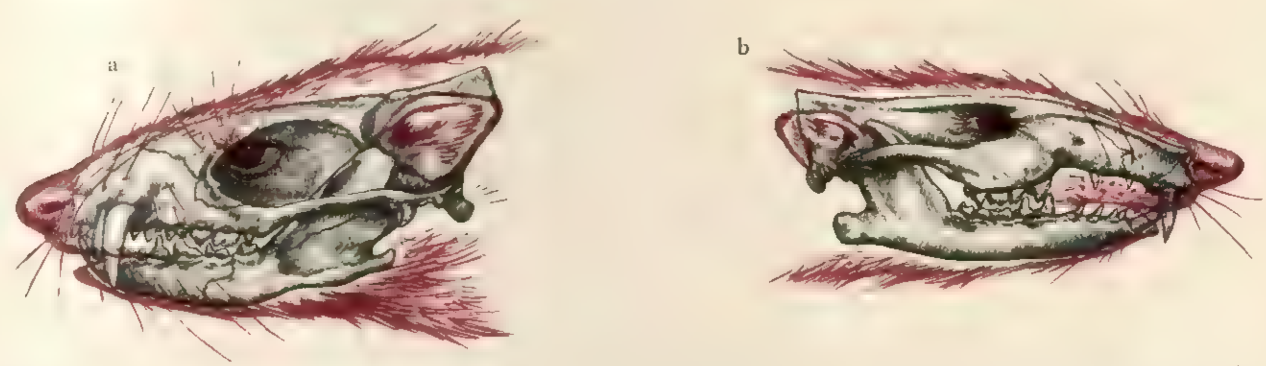
4



A MAMMAL OF THE CRETACEOUS—This illustration shows the skull of the multituberculate *Taeniolabis*. The multituberculates originated in the Jurassic, but reached their highest point of specialization during the Cretaceous. They survived into the Tertiary period before becoming extinct. The order Multituberculata endured for a longer period of time than any other order of mammals in the history of the Earth.

To summarize, the early evolution of the mammals was characterized by three phases or periods of adaptive branching: the first occurred in the Jurassic, when four orders became rather prominent; the second occurred in the Cretaceous, when the marsupials and eutherians appeared; and the third, at the beginning of the Tertiary, occurred when the marsupials and eutherians underwent extensive diversification and specialization.

5



PLACENTAL MAMMALS OF THE CRETACEOUS—Two types of eutherians or placental mammals are illustrated here. Both types, *Deltatherium* (Illustration 5a) and *Zalambdalestes* (Illustration 5b), were widely distributed during the Upper Cretaceous. These animals were quite similar to certain existing insectivorous mammals. In fact, certain animals with characteristics much like those of *Zalambdalestes* are still living today, especially on the island of Madagascar.

MARSUPIALS AND EUTHERIANS | the pouched mammals and the placental mammals

The history of the mammals began in the late or perhaps middle part of the Triassic period, but certain groups did not develop fully until the Jurassic. Among these groups were the subclass Allotheria, which included the multituberculates and perhaps the triconodonts, and the subclass Theria, which included the symmetrodonts and the pantotheres. Sometime early in the Cretaceous period two other groups evolved from the Theria. These groups, the Metatheria (including all marsupials or pouched animals) and the Eutheria (including all placental mammals), comprise most of the mammals living today. The Prototheria (including the monotremes or egg-laying mammals) constitute a group of animals that seem very primitive; however, the phyletic origins of this group are obscure, and fossil evidence of monotremes is of fairly recent age.

THE MARSUPIALS

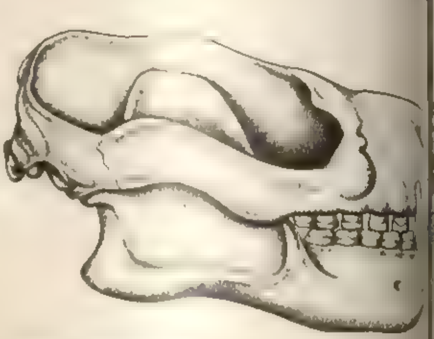
The metatherians or marsupials evolved from the pantotheres during the Cretaceous period, almost at the same time as the eutherians were developing along a different phyletic line. Today the marsupials constitute a small group of mammals in the Americas and in Australia; in Australia, the marsupials are the dominant terrestrial vertebrates.

AN INSECTIVORE—The hedgehog (*Erinaceus europaeus*) is one of the most common insectivores living today. Traces of primitive insectivores, the most ancient placental mammals, have been discovered in rocks formed during the Cretaceous period.

The present distribution of marsupials is closely related to the history of the continental landmasses during remote periods of geologic time. During the Cretaceous the marsupials were evenly distributed over all the continental masses. At that time, either the continents had not drifted apart or they were still connected in some manner—according to Wegener's hypothesis of continental drift. During the Cretaceous, therefore, scientists assume that the continents were still joined together so that the terrestrial vertebrates were able to diffuse widely. Near the end of the period, the placental mammals began to develop, and during the Cenozoic era these animals came into direct competition with the marsupials. The marsupials, less highly evolved than the eutherians, were forced into a rapid decline all over the Earth, with the exception of Australia and South America. Australia had just completed its separation from Asia, and the eutherians had not yet spread to this part of the world. Therefore, the marsupials had a vast area in which to live without competition from more highly evolved animals.

A similar situation existed in South America, which at that time separated from North America. Thus, for the whole of the Tertiary period, the marsupials were able to develop undisturbed in South America. Eventually, however, at the end of the Tertiary, the two American continents became reconnected, thereby permitting migrations of the specialized eutherians. The presence of the latter was the chief reason for the gradual elimination of most of the American marsupials. Nevertheless, during the Cretaceous and early part of the Tertiary, marsupials were fairly common in most parts of the world.

In general, marsupials are less highly evolved than eutherians. The former are characterized by a very short gestation period; the extremely small, immature offspring are born live and kept in a marsupium or pouch on the lower belly



PSITTACOTHERIUM—This animal belonged to the order Taeniodonta, a group of placental mammals of the Paleocene epoch. The taeniodonts had massive jawbones and stumpy teeth typical of herbivorous animals.

of the mother. The young complete their development while attached to teats inside the pouch. Both males and females possess special marsupial bones attached to the front of the pelvis; these bones, absent in the eutherians, serve to distinguish the skeleton of a marsupial from that of a placental mammal.

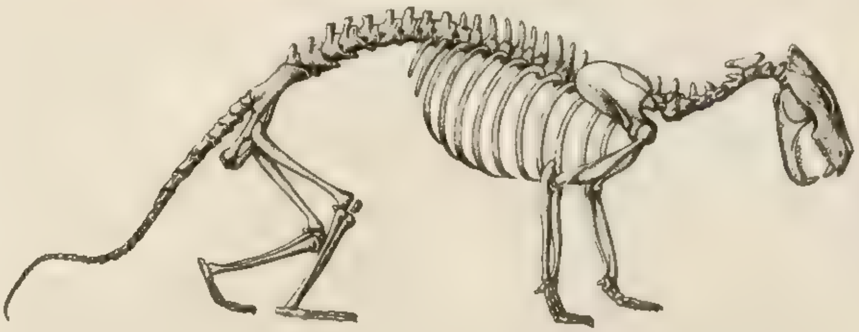
Marsupials have smaller brain cavities than eutherians, and the orbits are open at the back. Other features include a marked sagittal crest for the insertion of temporal muscles and a jawbone with a characteristic angular structure that turns inward. The teeth, consisting principally of triangular molars, vary considerably, depending on whether the animals are carnivorous or herbivorous.

Of present-day American marsupials, the opossum (*Didelphis*) is the best-known representative of an ancient group; as a matter of fact, the opossums are the only marsupials now living in North America.

According to an old and seldom used system of classification, marsupials having at least four incisors in the upper jaw were called polyprotodonts. *Didelphis* is a living example of the polyprotodont marsupials. *Prothylacinus* and *Thylacosmilus* were polyprotodont marsupials living in South America during the Miocene and Pliocene epochs, respectively. The latter is of particular interest, because it had two long canines in the upper jaw, which gave it an appearance similar to

A CURIOUS AUSTRALIAN OPOSSUM—The animal shown in this photograph belongs to the order Marsupialia, a group of mammals that originated during the Cretaceous period at about the same time as the eutherians or placental animals. Marsupials are considered more primitive than the eutherians, because the females bear their young prematurely and carry them in a marsupium or pouch until they have become more fully developed.

A MARSUPIAL OF THE MIOCENE—This illustration shows the skeleton of *Prothylacinus*, a carnivorous marsupial that lived in South America during the Miocene epoch. The marsupials, which were widely distributed throughout the world during the Cretaceous period, suffered a decline during the Tertiary. Today they exist only in a few areas of South America and on the continent of Australia; one genus continues to live in North America.



that of *Smilodon* (saber-tooth cat), an aggressive, carnivorous eutherian now extinct. In fact, *Thylacosmilus* has sometimes been referred to as the saber-tooth marsupial.

The largest-known marsupial was the *Diprotodon,* which lived in Australia during the Quaternary period. This animal, with a structure reminiscent of a giant ground sloth, belonged to the now extinct family Diprotodontidae, which lived in Australia exclusively.

THE EUTHERIANS OR PLACENTALS

The reign of the eutherians began near the opening of the Tertiary period. These animals were destined to become the most numerous of all the terrestrial vertebrates, and down to the present they have exhibited great powers of adaptive branching, producing forms perfectly adapted to both the sea and the air.

In contrast with the marsupials, the eutherians are characterized by a longer gestation period; the young pass through a relatively long period of prenatal growth and are born in an advanced state of development. Paleontologists are concerned with features of bone structure that may be observed in fossils. Perhaps the most significant feature of the eutherians is the development of the brain, as indicated by the size of the brain cavity; for the most part eutherians possess a far higher intelligence than the marsupials, because they have larger brains. As pointed out previously, the eutherians lack the epipubic or marsupial bones of the pouched animals, while the remainder of the postcranial skeleton is similar to that of their cousins and predecessors.

The teeth, especially the molars, are important in the study of the eutherians, for they form the basis of knowledge of eutherian evolution throughout geologic time, as well as the basis for the hypothesis that the eutherians descended from the pantotheres.

The infraclass Eutheria is subdivided into as many as 28 orders, 16 of which exist today.

THE INSECTIVORES

The order Insectivora includes the most ancient eutherians known, animals dating from the Cretaceous period. *Deltatherium* and *Zalambdalestes,* whose remains have been found in Mongolia, are two well-known extinct genera. The teeth of the pantotheres and the teeth of more highly evolved eutherians have reduced canines and more highl[illegible]veloped incisors. Among the mod[illegible] insectivores are the hedgehogs, mol[illegible]d shrews.

THE CHIROPTERANS

The order Chiroptera co[illegible]s of the only flying mammals, the bat[illegible]ese animals have adapted themselves [illegible]ight through a lengthening of three d[illegible] of the forelimb to support a thin m[illegible]rane that is

ORDERS OF EU[illegible]RIANS

Insectivora (hedgehogs[illegible]s, and shrews)
Chiroptera (bats)
Dermoptera (flying lem[illegible]
*Taeniodonta
*Tillodontia
Edentata (armadillos, [illegible]ers, and sloths)
Pholidota (pangolin)
Primates (lemurs, tarsi[illegible]onkeys, apes, and men)
Rodentia (rats, mice, sq[illegible], and other rodents)
Lagomorpha (rabbits a[illegible]res)
Cetacea (whales, dolphi[illegible]nd porpoises)
Carnivora (dogs, cats, b[illegible], and weasels)
*Condylarthra
*Notoungulata
*Litopterna
*Astrapotheria
Tubulidentata (aardvar[illegible]
Hyracoidea (hyraxes)
Proboscidea (elephants)
*Desmostyliformes
Sirenia (manatees and dugongs)
*Pantodonta
*Dinocerata
*Pyrotheria
*Xenungulata
*Embrithopoda
Perissodactyla (horses, tapirs, rhinoceroses, and other odd-toed ungulates)
Artiodactyla (hippopotamuses, swine, cattle, deer, giraffes, and other even-toed ungulates)

*extinct

attached to t· ly and the hind limbs. The bats us· hind limbs to cling to rocks or tre· characteristic upside-down positi·

In the for . of the skull and the teeth, the l· very similar to the insectivores which they probably descended . enetically. The most ancient foss: hiropterans are found in early Eo· posits.

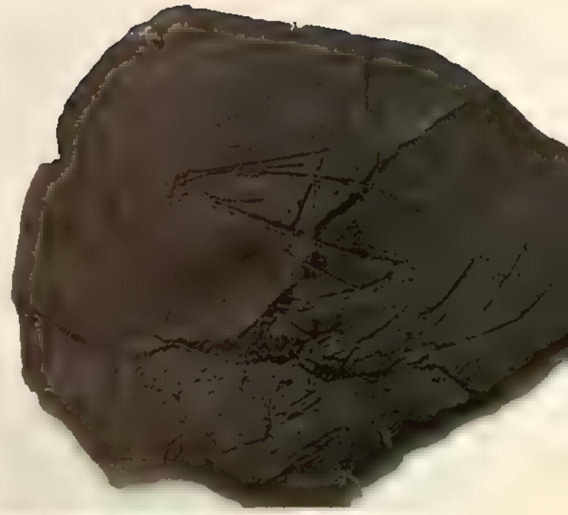
THE DER ERANS

The order D tera consists of a single genus, *Gal·* *us*, also classified as *Cynocephal·* Asiatic arboreal animal variously ca· he colugo, cobego, and flying lemu· nimal has a membrane extending b· its limbs and body, which enab· glide from trees, even from consid heights.

THE TAENIODONTS AND THE TILLODONTS

Mammals belonging to the orders Taeniodonta and Tillodontia are known only in fossil form. The taeniodonts, which had a phylogenetic connection with the primitive insectivores, appeared during the Paleocene epoch and became extinct during the Eocene. They possessed huge jawbones and the stumpy teeth characteristic of herbivores; their molars were rootless pegs and were distinguished by the presence of a limited band of enamel.

The tillodonts existed during the Eocene only. They were also similar to the insectivores and were equipped with large, chisel-like incisors, small canines, and molars that appear to have been adapted to a herbivorous or omnivorous diet.



ARCHAEOPTERОPUS TRANSIENS—This impression, discovered at Montereale in the Veneto, is the only trace of fossil bats found in Italy. This fossil comes from Oligocene deposits, but Eocene remains have been found.

SMILODON **·ING *HIPPARION***—*Smilodon californ·* s one of the so-called saber-tooth · group of carnivores characterized by enormously long canines in the upper jaw. Originating in the Oligocene epoch, these animals became extinct during the Pleistocene. *Hipparion*, a three-toed mammal related to the horse (but not ancestral to it), was typical of the Pliocene epoch.

THE PRINCIPAL ORDERS OF MAMMALS | a brief survey

A brief survey of the main orders of mammals provides background useful for understanding how these animals flourished during the Tertiary and Quaternary periods. Such a survey must include the orders Edentata, Primates, Cetacea, and Carnivora, as well as the various orders of ungulates or hoofed mammals.

THE EDENTATA

The sloths, anteaters, and armadillos are living members of the order Edentata. The name of the order literally means "toothless," but only the anteaters actually are without dentition; the sloths and armadillos have no teeth in front and very small teeth in back. Other characteristic features of the edentates are very long claws and a postcranial skeleton equipped with supplementary joints in the vertebrae.

At one time, the tillodonts, taeniodonts, tubulidentates (aardvarks), and pangolins (spiny anteaters) were classified as edentates. Today, however, these animals are assigned to separate orders, and the order Edentata comprises but a handful of living forms.

The edentates have existed since Eocene times. Very interesting extinct varieties have left traces of their huge skeletons in the Pliocene and Pleistocene deposits of South America. The *Megatherium,* a giant ground sloth, was certainly one of the largest edentates of its own or any time. Another curious creature, the *Glyptodon,* was an enormous armadillo-like animal that measured more than 4 m (about 13 ft) from the tip of its shielded head to the tip of its spiked tail; it was covered with a rigid armor plating.

THE CETACEA

The order Cetacea, which comprises the whales, dolphins, and porpoises, is of particular interest because it includes not only the largest animals that have ever lived, but also the mammalian forms that have best adapted to life in the sea. The adaptation to a marine existence involved several structural changes; the body took on a streamlin[illegible] fishlike shape, the forelimbs were adap[illegible] into paddles, and the tail was transfo[illegible]d into a horizontal tail fin. No exte[illegible]race remains of the hind limbs. The [illegible] is devoid of hair except for occasi[illegible] remnants on the snout and lower ja[illegible]

The earliest cetacea[illegible]earing during the Middle Eocen[illegible]re the now-extinct archaeocetes, w[illegible] had differentiated teeth. The od[illegible]etes, which had simplified teeth, ap[illegible]d during the Late Eocene; they ma[illegible]e descended from the archaeocetes [illegible]y cetaceans thrived in the Mediterr[illegible]n during the last part of the Tertiary[illegible]d, and some attained considerable s[illegible] Pliocene deposits in the Apennines [illegible]yielded fossils of these animals. [illegible]n must have died in shallow waters [illegible]e coasts of a gulf that then existed w[illegible] the Po Valley is presently located.

THE CARNIVORA

Mammals of the order C[illegible]ora are agile predators equipped wi[illegible]rong, sharp claws and teeth special[illegible] for feeding on flesh. Primitive carn[illegible]s known as creodonts appeared duri[illegible]e latter part of the Paleocene epoch [illegible] became extinct before the end of th[illegible]rtiary. *Oxyaena* and *Hyaenodon*, [illegible]n somewhat resembled modern hyen[illegible]vere typical creodonts.

More highly evolved [illegible]rnivores appeared during the Eocene and Oligocene epochs; they included the earliest fissipeds (animals with paws or pawlike feet), such as primitive bears, cats, dogs, and weasels. Fin-footed carnivores (seals and walruses), well-adapted for aquatic life, made their appearance during the Miocene.

Among the bears, *Ursus spelaeus* (cave bear) was an interesting specimen that lived during the last Ice Age of the Quaternary. Typical of the felines were the great saber-tooth cats, such as *Dinictis* and *Eusmilus* of the Oligocene and *Smilodon* of the Quaternary; all these animals were distinguished by excessively long canines in the upper jaw.

1

a

THE EDENTATES—Representatives of the order Edentata have lived on the Earth since Eocene times. Interesting remains in the form of huge skeletons have been discovered in Pliocene and Pleistocene deposits. *Megatherium americanum* (Illustration 1a), which attained a length of 6 m (about 20 ft), was as big as an elephant. *Mylodon* (Illustration 1b) was another Pleistocene representative.

b

2

CAVE LION—This photograph shows the entire skeleton of *Felis spelaea*, a Pleistocene cat whose remains have been discovered in many European caves.

RHINOCEROS OF THE PLIOCENE—The family Rhinocerotidae appeared during the Eocene and, in the course of time, gave rise to many forms quite different from present-day forms. Among them was the gigantic *Baluchitherium*, which lived during the Oligocene and Miocene epochs. The Pliocene specimen whose skeleton is shown here was quite similar to the modern rhinoceros.

3

HOLOPHONEUS ROBUSTUS—This animal was another member of the cat family. One of the early saber-tooth cats, this feline lived in North America during the Oligocene epoch. It was characterized by abnormally developed upper canines, reduced lower canines, and an apophysis growing downward from the tip of the jaw.

4

THE UNGULATES

The term *ungulate* is used here for convenience, although it is no longer used in zoological and paleontological classification. Ungulates or hoofed mammals actually belong to a number of different orders.

The order Condylarthra was one of the most primitive groups of ungulates, and its representatives were most common during the Paleocene and Eocene epochs. These five-toed animals possessed a number of creodont and carnivore features. The widely studied *Phenacodus* was typical of the condylarths, which may have been progenitors of several other ungulate orders.

Mammals belonging to the order Litopterna were also rather primitive. In the specialization of their teeth and the reduction in the number of pedal digits, the litopterns resembled horses.

Another important extinct order, Notoungulata, was represented in South America from the Paleocene to the Quaternary. Notoungulates possessed teeth specialized for a herbivorous diet; their limbs were more general, but the number of functional digits was reduced to two or three. One of the largest genera of this order was *Toxodon*, remains of which have been recovered from Pleistocene deposits.

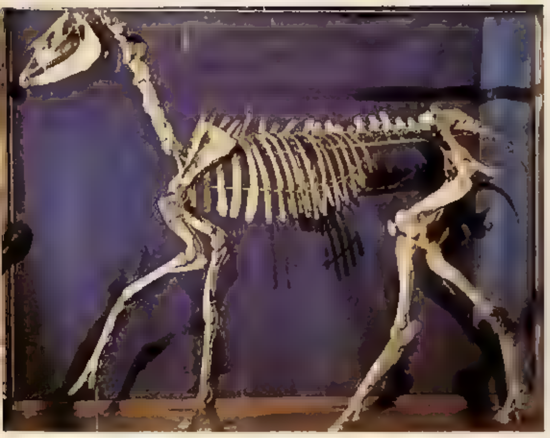
The order Astrapotheria consisted of large mammals with short elephantine trunks. Members of the order, exemplified by *Astrapotherium*, lived from the Paleocene to the Miocene in South America.

All of the aforementioned orders of hoofed mammals are now extinct, as are the orders Pyrotheria, Xenungulata, Pantodonta, Dinocerata, Demostylia, and Embrithopoda. The pyrotheres were giant herbivores with elongated proboscises, which lived in South America during the early parts of the Tertiary. The xenungulates, residents of South America during the Paleocene, were represented by a single genus, *Carodnia*. Herbivorous pantodonts, exemplified by *Coryphodon*, lived during the Paleocene and Eocene epochs. The order Dinocerata included the colossal uintatheres of the Paleocene and Eocene. Desmostyles were heavy, amphibious mammals somewhat resembling the modern hippopotamus; they lived during the Oligocene and Miocene epochs. The order Embrithopoda consisted of enormous, highly specialized African animals of the genus *Arsinoitherium*.

To conclude this short summary of mammals, mention must be made of the order Proboscidea, which comprises the modern elephants and their ancestors, and the most highly evolved orders of ungulates, Perissodactyla and Artiodactyla.

The perissodactyls include the horses, tapirs, rhinoceroses, and their fossil relatives. The evolutionary history of the horse family is probably better known than that of any other mammal. The line began during the Eocene with forms about the size of foxes; in time, the early horses increased considerably in size and changed their habitat from forest to grassland. In the course of this evolution,

5



PRIMITIVE RELATIVE OF THE HORSE—*Hipparion gracile* appeared during the Miocene and was quite common in the Pliocene. This animal, about the size of a zebra, had relatively modern forms; the second and fourth digits of the feet were rudimentary. During the Miocene, *Hipparion* migrated from North America to Asia and thence to Europe.

the number of toes was reduced from five to one, and the teeth became increasingly specialized.

The now extinct titanotheres (brontotheres) left a fossil record that can be traced step by step from the Eocene to the Oligocene; this record indicates that they evolved from small animals to gigantic beasts in an extraordinarily short period of time.

Primitive tapirs and rhinoceroses—or progenitors of these animals—appeared during the latter part of the Eocene; during the course of their evolution, they produced many extinct forms that differed greatly from modern representatives. One of the most famous members of the rhinoceros family was the hornless *Baluchitherium*, which attained a height in excess of 5 m (about 16 ft) and was the largest terrestrial mammal that has ever lived.

From the paleontological point of view, the artiodactyls are much less interesting than the perissodactyls. The order Artiodactyla includes members of the swine, peccary, hippopotamus, and camel families, as well as all the ruminants, such as antelopes, cattle, deer, giraffes, goats, and sheep. Many extinct animals are also considered members of this order; among them are the paleodonts, which lived during the Eocene, Oligocene, and Miocene epochs.

THE PRIMATES

During the Paleocene epoch, primate-type animals branched out from the insectivores, following a path of gradually increasing adaptation to an arboreal existence. Characteristics of evolutionary importance include the development of great mobility of all the limbs and general agility of movement; development of opposable thumbs and big toes; a gradual increase in the power of sight at the expense of the sense of hearing; an increase in the size of the brain; and a general adaptation toward an upright posture.

The study of the more recent primates is the business of paleoanthropology, the science that investigates the origins and development of men—problems so vast and full of interest that they can scarcely be hinted at here. Space permits but a glimpse at the most primitive primates, which were still quite close phylogenetically to the insectivores. Both lemurs and tarsiers appeared during the Eocene epoch, but pursued different evolutionary paths. *Notharctus*, whose remains were discovered in Eocene deposits in the United States, was a rather highly evolved lemur, very similar to modern lemurs. *Tetonius*, whose remains date from the Lower Eocene ... sessed a skull almost identical to that ... *arsius*, which lives in the forests of I... ...esia and the Philippines.

THE BRONTOTHERIUM—The titanotheres, members of the order Perissodactyla, existed for a relatively short time (about 55 million years); in that time, however, they evolved from small forms into gigantic beasts with great horns, such as *Brontotherium* of the Lower Oligocene epoch.

6

7

EARLIEST REPRESENTA... OF THE HOMINIDS—The fossil of *Or... ...ocus bambolii*, shown here in relief, was ...vered in Upper Miocene deposits in Italy ... considered by some paleontologists to t... earliest known specimen of a hominid.

The earliest fossils of the higher primates have been recovered from the Oligocene deposits at Fayyum in Egypt. Among these fossil representatives of the primitive monkeys are *Oligopithecus*, *Parapithecus*, and *Propliopithecus*. It is likely that they belong to the ancestral stock that gave rise to both anthropoid apes and catarrhine monkeys. The most ancient of the primates from the Egyptian Oligocene is *Oligopithecus*, probably more than 30 million years old. This creature had the same lower dental formula as the modern catarrhine monkeys, but the molars were very primitive.

THE STORY OF THE CETACEANS | whales, dolphins, and porpoises

Since the be[illegible] ng of the Cenozoic era, about 65 to [illegible] lion years ago, animals have gradua[illegible] sumed forms and appearances v[illegible] creasing similarity to those of pre[illegible] y animals. The mammals in part[illegible] have undergone relatively rapid [illegible] tion, and the various forms have [illegible] ces of their existence in the rocks [illegible] Earth. Paleontologists, therefore, a[illegible] le to determine when certain mam[illegible] first appeared, and they are often ab[illegible] o further back in time and identify [illegible] ancestors of these animals. The ev[illegible] on of some animals—the horse, the w[illegible] and the kangaroo, for example—ha[illegible] n traced step by step.

A detailed [illegible] nstruction of evolutionary develop[illegible] is not possible in the case of spo[illegible] chinoderms, and other animals th[illegible] ve evolved slowly. In fact, scient[illegible] ust go back in time many millions of [illegible] to find species substantially differ[illegible] m those in existence today. Mammals, of course, evolved with lightning speed during the Tertiary and Quaternary periods, and their original progenitors were astonishingly different from modern mammals. The horse is a typical example, beginning as a very small animal and gradually acquiring the size and structural characteristics it exhibits today.

REMARKABLE ANIMALS

Of all the stories of animal development, perhaps the most extraordinary and fascinating is the story of how certain mammals, the cetaceans, adapted themselves to a marine existence.

For a variety of reasons, much research has been devoted to these animals. Certain types of whales have been hunted and killed so extensively that they are in danger of extinction; therefore, scientists have undertaken intensive study of the habits and behavioral patterns of these animals.

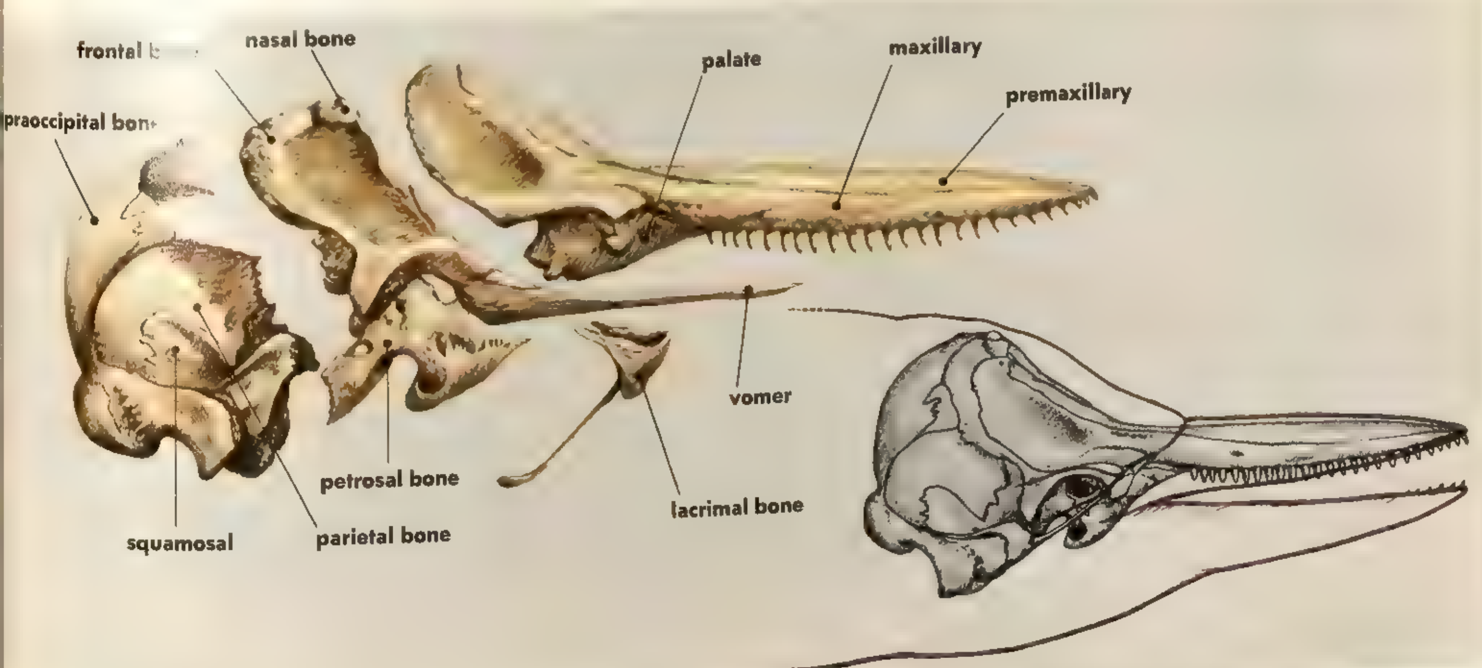
The dolphins in particular have been subjects of recent investigations, because they possess a degree of intelligence that seems as high as, or higher than, that of the primates—and second only to that of man. The dolphin also has a skin that enables it to control the film of water with which it is in contact while swimming. This film of water causes friction; by controlling the film of water, the dolphin can control the friction, and hence, its swimming speed.

Various studies are also being made of the learning abilities of dolphins and of the manner in which these animals produce and hear sounds. Apparently they can make and receive a wide range of sounds, and they seem to have exceptional hearing. Indications are that dolphins and whales utilize sounds in a form of echo location somewhat similar to that

1

A CASE OF [illegible] **ODD CRANIAL BONES**—In any evolutio[illegible] process, certain important parts of the [illegible] my (such as the skeleton) normally un[illegible] drastic changes. However, few if any [illegible] ructures have undergone a more total transformation than the skulls of cetaceans. As a result of a telescoping process, the nasal, premaxillary, and maxillary bones moved backward and upward until they were superimposed; this phenomenon is found in the cetaceans only. The exploded view of the skull of *Tursiops truncatus* (Illustration 1a) shows the effect of superimposition. Illustration 1b shows the thickness to which the maxillary is superimposed on the frontal.

a



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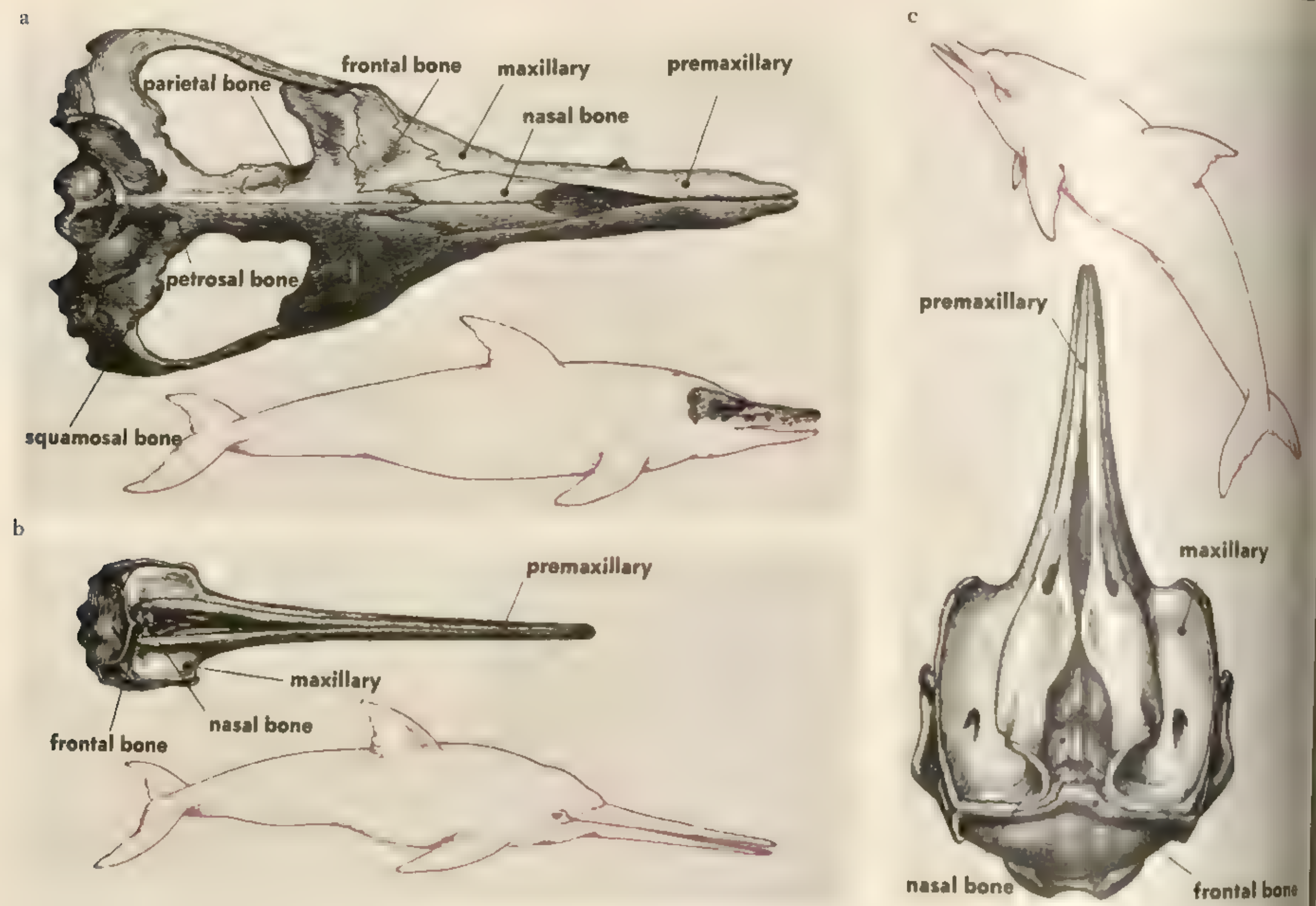


EVOLUTION OF THE CETACEAN SKULL— This series of illustrations indicates the way the skulls of cetaceans have evolved since the beginning of the Eocene epoch. The skull of a cetacean such as *Dorudon osiris* (Illustration 2a) can scarcely be distinguished from the skulls of the most primitive Mesozoic ichthyosaurs. *Dorudon* and the fishlike reptiles also had virtually the same marine habits and hunted practically the same prey.

The greatly elongated skull of *Argyrocetus patagonicus* (Illustration 2b), which lived during the Miocene, was somewhat similar to the skull of the modern dolphin. It was characterized by an unusually long jaw.

The skull of *Delphinodon dividum* (Illustration 2c) was closer yet to that of the present-day dolphin. It was still somewhat flat, and the snout was comparatively short and broad.

used by bats in locating food and avoiding obstacles. Some scientists are attempting to learn whether or not the cetaceans have developed some system of communication.

Without exception, the cetaceans are excellent swimmers, and they are able to remain underwater without breathing for up to an hour. They descend at times into the depths of the ocean and seem capable of adjusting easily to differences in pressure. The odontocetes (toothed whales) are ferocious fighters. Strangely enough, the larger whales (the mysticetes) are equipped, not with teeth, but with baleen or whalebone, which functions as a sieve in the capture of plankton, the chief constituents of their diet.

Despite its relatively small size, the dolphin protects itself against most of the dangerous kinds of sharks. The killer whale, which is larger than the other dolphins, uses its outstanding strength and intelligence to hunt down various kinds of prey. Its only superior is the enormous sperm whale, which hunts for cuttlefish and squid in the deepest parts of the ocean. The blue whale is not only the largest living mammal, but also the largest animal that has ever lived; it may attain a length of about 30 m (about 100 ft) and a weight of 150 tons, exceeding even the colossal saurians of the Mesozoic era.

The cetaceans originated on dry land, where they lived as small terrestrial animals. They underwent an evolution that led them to diversify from the original species in an unusually explosive manner. Their bodies became smooth and streamlined and became increasingly similar to the bodies of fish or ichthyosaurs. The most spectacular evidence of change is supplied by the bones of the skull, which became deformed in a particular way (see Illustration 1).

The cetaceans first appeared during the Tertiary and the various species were formed at that time; they have not evolved appreciably during the Quaternary.

3

A DOLPHIN [illegible] **IE MIAMI SEAQUARIUM**—Members [illegible] enus *Tursiops* are called bottle-nosed dolphins. Most dolphins have a dorsal fin and a great number of teeth.

THE KILLE[illegible]**LE**—This photograph was taken thro[illegible] glass of an aquarium. The killer whale, *Orcinus orca*, is the largest and strongest member of the dolphin family.

4

5

A BOTTLE-NOSED DOLPHIN EMERGING FROM THE WATER—All the cetaceans are fast swimmers. Because they are air-breathing mammals, they must surface periodically; however, they can remain submerged for relatively long periods of time.

THE PERISSODACTYLS | horses, tapirs, and rhi· ceroses

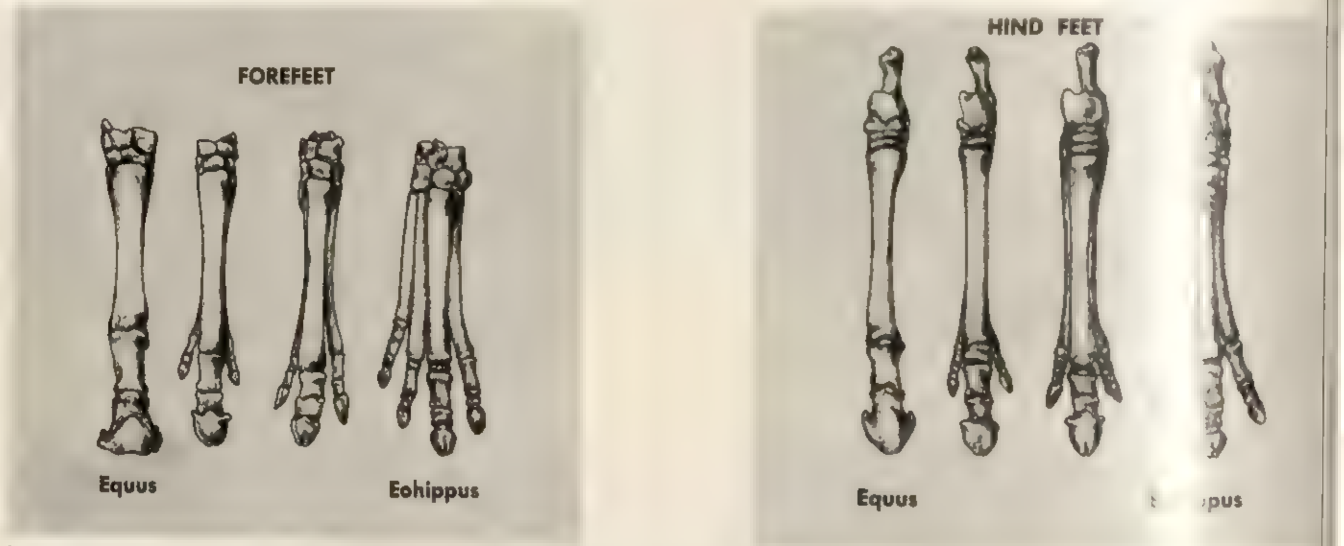
The term *perissodactyl* generally connotes an odd number of digits, and mammals of the order Perissodactyla are characterized by an odd number of functional toes. In all of these animals, the axis of the foot extends through the middle toe, whereas in the artiodactyls (the so-called even-toed mammals), the axis passes between the third and fourth toes.

The perissodactyls originated in the Eocene epoch of the Tertiary period. The order has been subdivided into two suborders, Hippomorpha and Ceratomorpha. The hippomorphs comprise three superfamilies: Equoidea (horses and extinct paleotheres), Brontotherioidea (extinct titanotheres), and Chalicotherioidea (extinct chalicotheres). The ceratomorphs consist of two superfamilies: Tapiroidea (tapirs and their extinct relatives, isectolophids, helaletids, and lophiodonts) and Rhinocerotoidea (rhinoceroses and extinct rhinoceroslike animals known as hyrachids, hyracodonts and amnyodonts).

Of all the perissodact· the only surviving groups belong the families Equidae, Tapiridae, and ·inocerotidae. The horses receive speci· ·tention here, because their fossil reco· · so complete that their evolution · been reconstructed in great detail. ·eover, horses were directly involved ·ith primitive men, providing them w· ·heir first useful means of swift trans· ·tation.

1

a

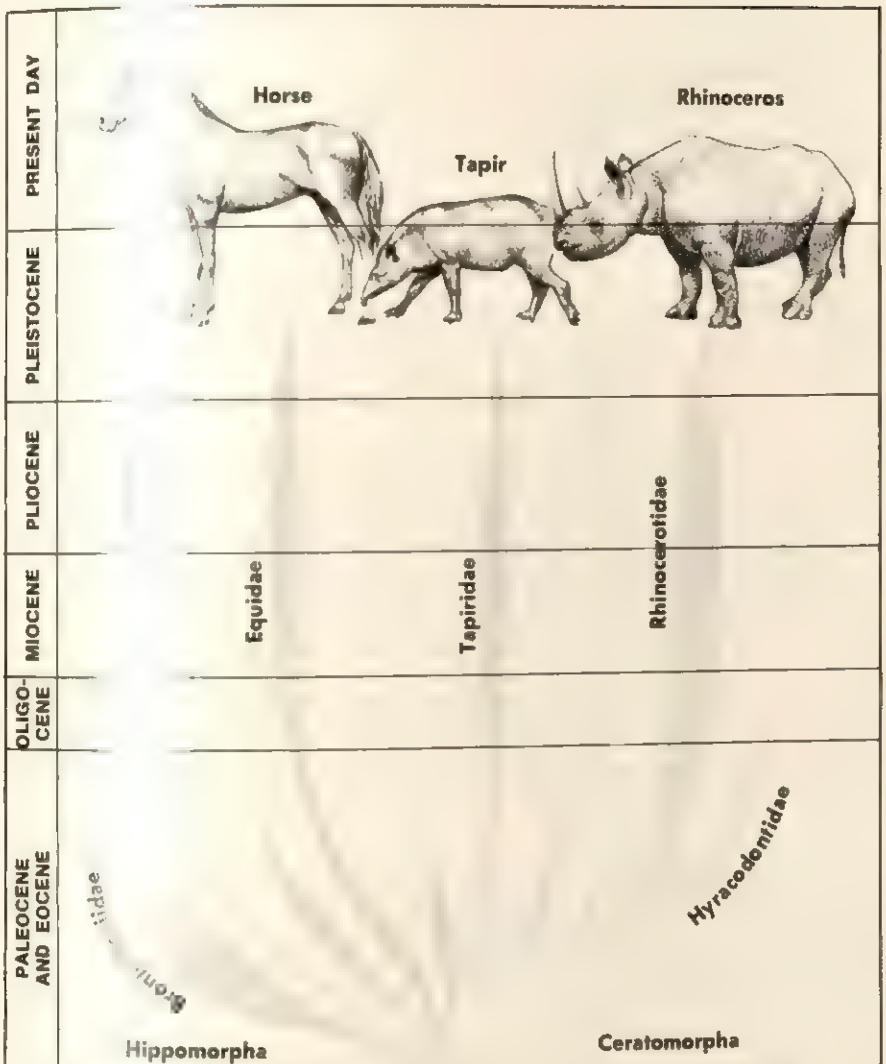


CHARACTERISTICS OF PERISSODACTYLS— The perissodactyls appeared near the beginning of the Tertiary period, during the Eocene epoch, and with a certain variety of mutations they have been evolving steadily until the present day. Horses, zebras, tapirs, and rhinoceroses are modern perissodactyls descended from Eocene forms. Certain features of perissodactyls have been characteristic from the beginning of their evolution. The most important features were their herbivorous habits and their tendency toward large forms. (The extinct titanotheres were the largest perissodactyls of all.) The fact that the perissodactyls were herbivores is evident from their teeth; from the beginning, they possessed a ring of incisors, typical of the herbivores, with the canines and premolars located behind them. A gap still remains between the incisors and the molars. The teeth in effect demonstrate a double specialization: the incisors are suited for cutting vegetable fibers and the broad, flat-crowned molars are adapted for chewing the fibers. The specialization of the molars is one feature that distinguishes the perissodactyls from the artiodactyls, for the latter have quite underdeveloped molars.

However, the most distinguishing mark of the perissodactyls is the · ·nce of an odd number of digits on the · feet. In most cases, the forefeet also h· ·n odd number of digits, but in certain f· forms the fifth digits of the forefeet were · ·tially atrophied. Illustrations 1a and 1b show (from right to left) the evolution of the feet of some very typical perissodactyls, members of the horse family. What generally happened was that the first and fifth digits disappeared, leaving the three middle toes intact. In the horse itself (*Equus*), the foot lost all lateral digits, and the central digit alone remained. This digit was equipped with a nail of unusual size—the horse's hoof.

The perissodactyls reached the peak of their evolutionary history about 30 million years ago, when they were the dominant hoofed animals in most of the world. They held about the same position then that deer, antelope, and oxen do now. After the Middle Tertiary, the perissodactyls declined rapidly. Of the 12 families that lived at the peak of their radiation, only nine survived into the Oligocene epoch, and four of those died out before its end. At the peak of their development, the perissodactyls apparently were highly evolved and intelligent. The reason for their decline is unknown.

2



THE EVOLUTION OF THE PERISSODACTYLS—The history of the development of the perissodactyls has been traced from the distant Eocene epoch down to the present day. This history may be divided into three principal phases.

The first phase extended from the earliest times down to the end of the Eocene. During this span of time, an evolutionary explosion occurred, with many families of perissodactyls appearing and most of them becoming extinct by the end of the Eocene.

In the meantime, two characteristic evolutionary directions emerged: certain animals, the so-called hippomorphs, began to evolve into horselike forms, while the animals known as ceratomorphs began to evolve in the direction of the present-day tapirs and rhinoceroses.

The second phase of evolution, embracing the Oligocene, Miocene, and Pliocene epochs, witnessed two main phenomena, apart from the disappearance of many species that had reached the limits of their capacity for further adaptation. At first a number of species attained gigantic size, as in the case of *Titanotherium*. Later on, the forms became simpler but far more refined. The most important feature of this second phase of evolution was the emergence of all the principal perissodactyl forms that still exist today.

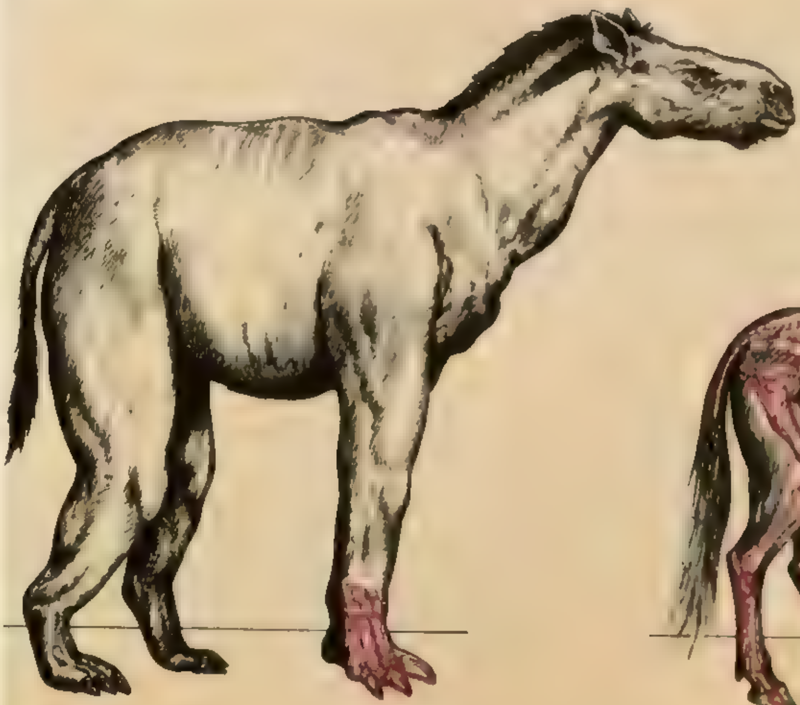
The third phase corresponds to the present period, the Quaternary, the last two million years or so of Earth history. For obvious reasons this is the best-known phase; what is more, nearly all the animals existing at the outset of the Quaternary have survived.

The evolution of the horse has been clear-cut, vigorous, and rapid. It has produced highly specialized forms observed in certain species of horse today; actually the specialization of form has been common to the whole evolutionary line of the perissodactyls. For example, all these odd-toed ungulates have undergone a general increase in size and a lengthening of the limbs, characteristics that have made them more agile than their predecessors. The teeth have been generally modified, the hind legs have become stronger, and the skull is longer.

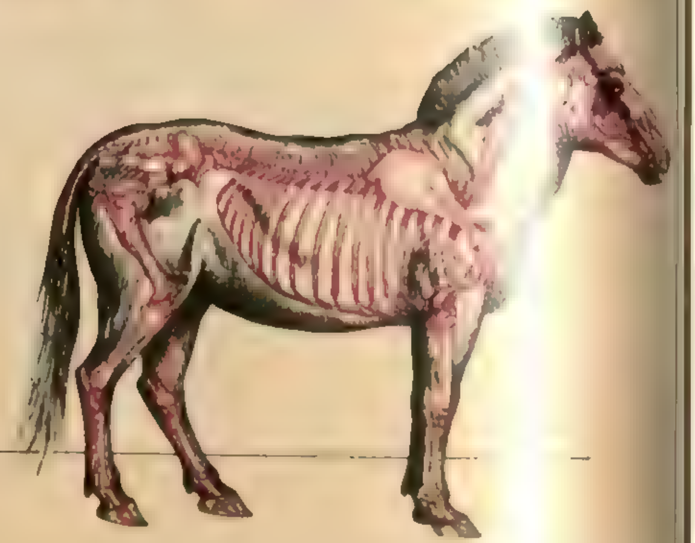
3

WILD HORSES OF THE STEPPES—This photograph shows a herd of Przhevalsky's horses in their natural habitat in Mongolia. Living on the wide-open stretches of the steppes, these wild horses wander about in small herds, able to move for hundreds of miles almost undisturbed by man, who sometimes hunts them but cannot tame them. Today they are very rare.

4a



4c



4b

CHALICOTHERIIDAE AND EQUIDAE — The chalicotheres (suborder Hippomorpha) originated during the Eocene and died out completely during the Pleistocene. *Moropus* (Illustration 4a) was an interesting if somewhat bizarre representative of this group from the Miocene epoch. In general size and shape, it was similar to a horse, except that its forelegs were longer than its hind legs. The structures of the skeleton and skull indicate clearly that this animal was a perissodactyl, but the structure of the feet was extremely curious and individual, for *Moropus* had long claws instead of hooves. For a long time, the fragments of the skeleton and the fragments of the feet were thought to have come from two different species.

The horses, the most highly evolved of the perissodactyls, originated during the Eocene, and the story of their evolution is well known. The first forms were very small, barely reaching a height of 50 cm (about 20 in.). Illustration 4b shows a reconstruction of one of them, *Hyracotherium* (less correctly designated *Eohippus* or dawn horse), which was widespread in Europe and North America and was the most ancient ancestor of the horse. *Mesohippus* and *Miohippus*, which lived in the Oligocene, were even larger, and *Merychippus* was the size of a pony. Finally, in the Pliocene *Pliohippus* evolved; this animal had a shape like that of the modern horse. Its feet had one digit only, its brain case was expanded, and its teeth were highly specialized.

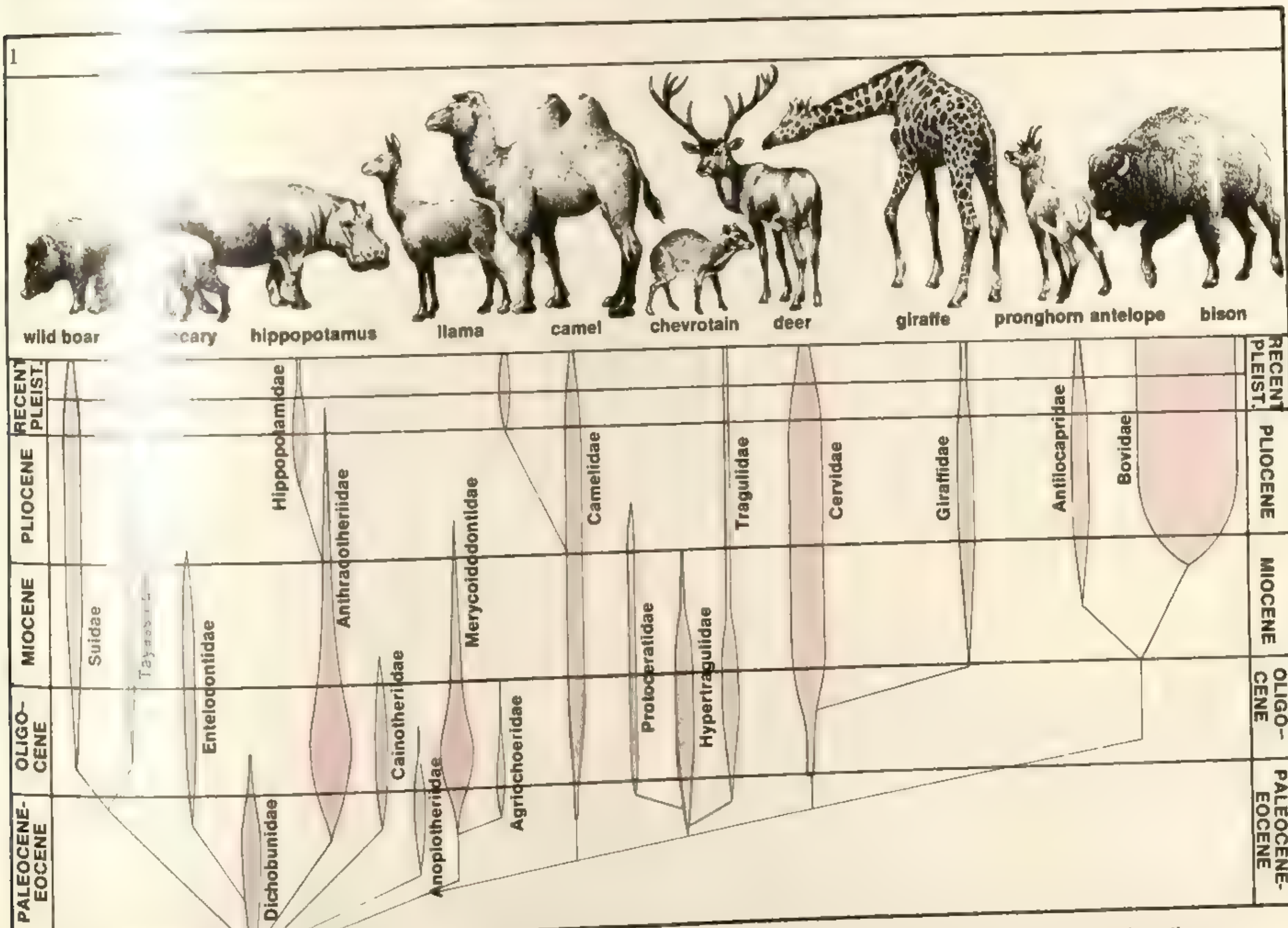
Pliohippus gave rise to the genus *Equus*, which has survived to the present day.

THE ARTIODACTYLS | the even-toed ungulates

The artiodac constitute perhaps the most import rder of mammals that appeared du he Tertiary period and survived int lern times. Having become differ ed into innumerable species, they now found on all the continents. T ghout their evolution they have sh an enormous degree of adaptability nding even to the smallest changes vironmental conditions. Moreover, w ever ecological conditions have been favorable, they have had no trouble in populating vast areas of the land. Although the number of wild artiodactyls is being drastically reduced today by the spread of civilization, and although rearing them in captivity tends to weaken them, they still remain one of the most important sources of protein for the human race.

Some artiodactyls are now in danger of extinction, but until a few decades or a few centuries ago they claimed a huge number of species. The American bison is a well-known example of an animal that once existed in very large numbers but that is now practically extinct. When the early settlers first moved West, about 60 million bison populated the prairies of North America. Now only a few thousand exist. Only very timely conservation measures averted the complete eradication of these animals.

1

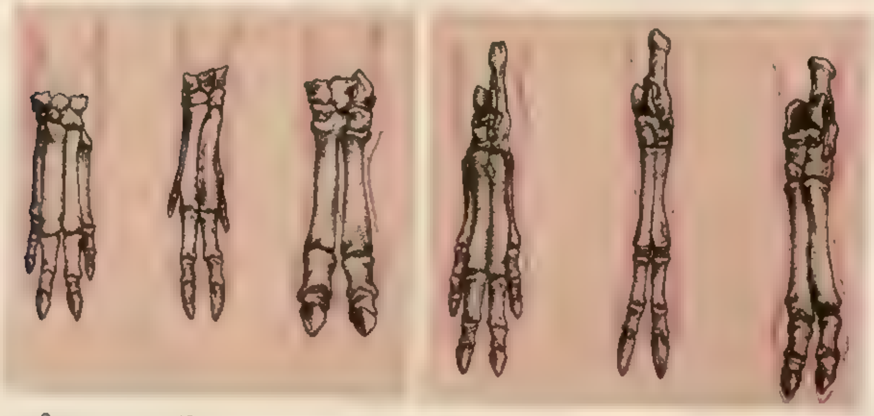


AN ORDER IN CONTINUAL EXPANSION—Almost from the beginning of the Tertiary period the order Artiodactyla has been expanding, increasing the numbers of its suborders and families, its species, and its individuals. At the beginning of the Oligocene epoch, a rigorous selection process greatly reduced the number of families in this order, but the loss was amply compensated in later epochs, especially the Pliocene, when many other families appeared. These families have survived to the present day and now populate all parts of the Earth.

A comparison may be drawn between the artiodactyls that disappeared halfway along the road of evolution and those perissodactyls that suffered the same fate almost at the same time. The present-day members of both orders are, as it were, rough copies of those that have carried over into modern times.

In reference to the illustration, mention should be made of the fact that the family Bovidae includes domestic cattle, sheep, goats, and gazelles, as well as bison. Similarly, the family Giraffidae includes okapis as well as giraffes. The llamas are an offshoot of the camel family.

2



2a 2b 2c 2a′ 2b′ 2c′

FEET WITH AN EVEN NUMBER OF DIGITS—A feature of prime importance in the classification of the artiodactyls is the fact that their feet have an even number of digits. The hooves of artiodactyls vary from those characteristic of large, heavy animals to those typical of light, swift ones. The layman visiting a zoo may compare the hoof of a hippopotamus, with its four big digits, and the hoof of an antelope or other artiodactyl that is adapted for long journeys or swift flight.

The skeletal structure of the artiodactyls has many additional characteristic features. However, all species possess one feature in common—strong hind legs. In many cases the muscles of the hind legs exhibit really exceptional development; these muscular hind limbs enable these animals to jump a great distance or to run uphill at great speed. This feature is particularly noticeable in species adapted to life in the mountains.

Illustrations 2a and 2a′ depict the fore and hind hooves, respectively, of *Bothriodon*, a member of the family Anthracotheriidae. Other animals represented in the drawings are *Mylohyus*, a peccary (Illustrations 2b and 2b′), and *Dinohyus*, a Miocene entelodont (Illustrations 2c and 2c′).

Deer present a completely different set of circumstances. These animals are estimated to number 100,000 in the state of Oregon alone. Forest authorities are often forced to kill a number of them periodically to prevent overpopulation and the consequent destruction of underbrush and young trees. Hunting for sport alone does not reduce the deer population enough to guarantee the ecological balance of the area.

In South America herds of peccaries roam the pampas at the foot of the Andes; often entire herds must be exterminated by helicopter-borne hunters armed with machine guns. Otherwise these animals would not only ruin the crops, but also would menace the lives of men and other animals.

In Africa, despite the slaughter carried out by poachers, hunters, and the hungry, and despite the fact the animals of great size are more seriously menaced by extinction than small animals, hippopotamuses are still numerous. The pygmy hippopotamus, however, is becoming rarer.

3

THE EVOLUTION OF THE S… …L AND TEETH—The skulls of artiodac… provide considerable information abo… ese important mammals. Examples show… re include *Archaeotherium* (Illustration… *Archaenodon* (Illustration 3b), *Bothriodo*… lustration 3c) and *Hippopotamus* (Illustra… 3d).

The primitive artiodacty… ad teeth that were similar to those of any… mon reptile of the Mesozoic era. The te… were generally pointed and relatively stron… they were not widely differentiated. Before… g. certain features appeared—features… n due course would be shared by all th… odactyls. The molars and premolars bec… ground down until they were flat and… broad, strong crowns. A gap appeared be… on the canines and the premolars, and in… t species this gap was never filled. Th… isors became adapted for cutting throug… plant stalks. Up to this point, little diff… e existed between the teeth of the arti… tyls and those of the perissodactyls.

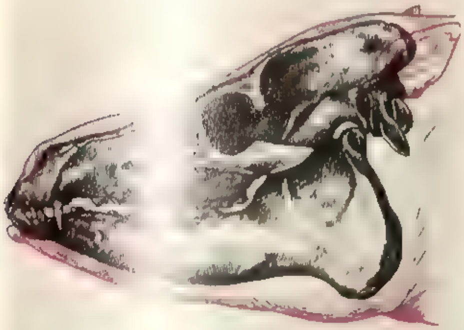
a

b

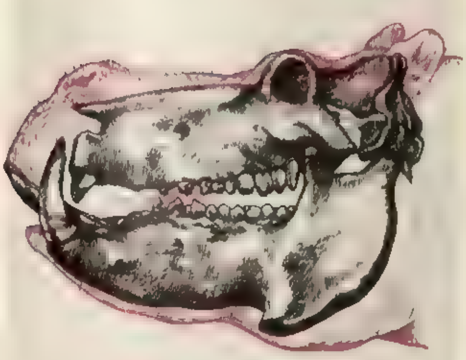
One denta cteristic of present-day ar-
tiodactyls is upper incisors are usually
weaker than wer ones, and sometimes
they are mis together. When the upper
incisors are , the lower incisors strike
against a ca l crown. These lower in-
cisors often le considerably to form an
effective cut stem.

The canin important features, which
in some artic s are enormous and saber-
like. Membe e swine, peccary, and hip-
popotamus f use their large canines in
defense, an sionally these animals are
quite aggres some artiodactyls the ca-
nines are m maller and function only in
the digging ts or the chewing of plants.
Most artioda with small canines defend
themselves nning away or by charging
their enemi using their big horns or
antlers. In t pecies equipped with horns
or antlers, t ull is considerably strength-
ened in the p that bear the weight of these
bony proce

c



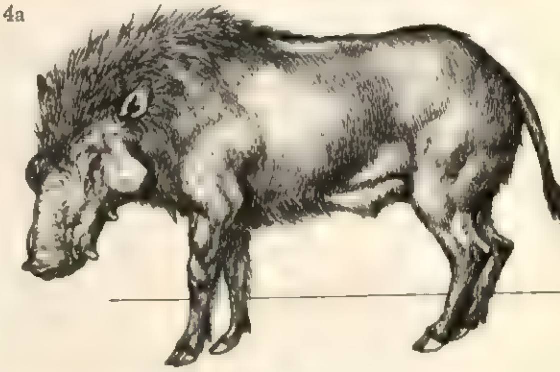
d



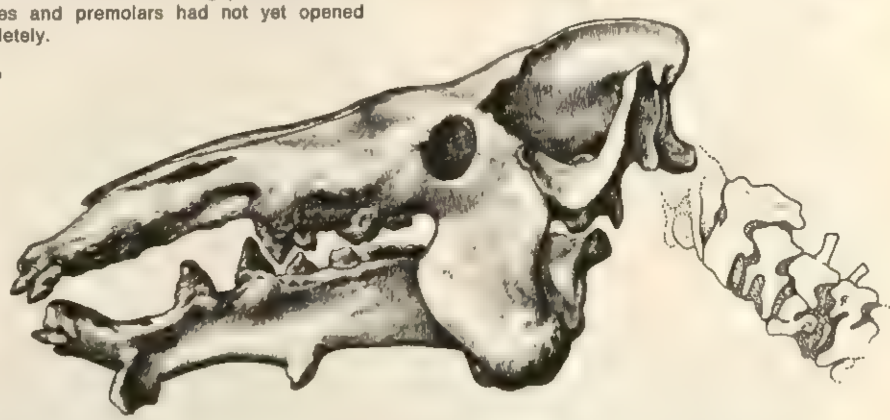
EARLY ARTIODACTYLS — The history of the artiodactyls is interesting, but complicated because of the vast number of families into which they have been divided. One of the earliest families, the now extinct Entelodontidae, made its appearance during the Eocene epoch of the Tertiary period. The entelodonts retained their relatively primitive features into the Miocene epoch, at which time they grew to be as large as bison.

The reconstruction of *Archaeotherium mortoni* (Illustration 4a) clearly shows the archaic features of this entelodont. It had very large incisors (the upper ones shorter than the lower ones), large canines that had not yet become saber-shaped, and premolars that had not yet flattened out. The gap between the canines and premolars had not yet opened completely.

4a

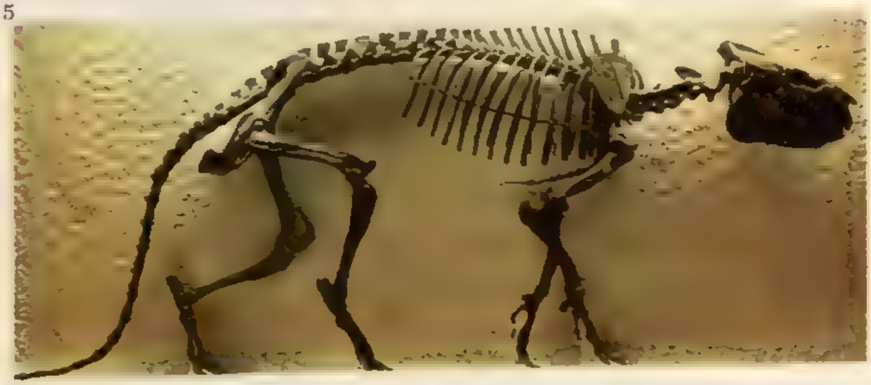


4b



Even more archaic were the features of *Megachoerus zygomaticus*, whose reconstructed skull is shown in Illustration 4b. This animal had two enormous protuberances on the side of the face, a very long skull, and most important, a set of teeth that were more reminiscent of a carnivore than of a herbivore. *Megachoerus zygomaticus* was probably an omnivorous animal with carnivorous tendencies. Although it was a rather large animal, the rest of its bodily structure bore a certain resemblance to a modern member of the swine family.

5



MERYCOIDODON—The animal whose skeleton is shown here belonged to the family Merycoidodontidae, which lived in a few areas of North America from the Eocene to the Pliocene epochs. Some had large claws instead of hooves; others had short trunks, as can be deduced from the reduction of the nasal bones and the shortening of the cranial bones.

ARTIODACTYLS OF THE PRESENT DAY | some modern representatives

The history of the most important groups of artiodactyls may be traced back to the Eocene epoch and in some cases to the Paleocene epoch. This history has been interwoven with all the important ecological events of the Tertiary and Quaternary periods, including the events associated with the development of human civilization. Artiodactyls are native to all continents except Australia and Antarctica. Some representative members, such as swine, deer, and buffalo, are also indigenous to many la lands except New Guinea, New Ze l, Tasmania, and those of the an ic region. Farm and game artiodact ave been introduced into most part the world where suitable fodder is ble.

1

THE SWINE — Present-day Suiformes include the families Suidae (pigs and wild boars), Tayassuidae (peccaries), and Hippopotamidae (hippopotamuses). Ordinarily, only the members of the family Suidae are called swine, but for the purposes of this discussion the peccaries will also be considered swine or swine-like animals.

The skulls of certain primitive artiodactyls such as *Perchoerus* were very similar to the skulls of the main species of wild pigs living today and even to the skulls of ordinary domesticated pigs. Paleontologists have found the similarity so great, in fact, that in order to speak of evolution from the Eocene to the present, they must refer to related families that are now extinct, such as the Entelodontidae. The entelodonts were indeed like modern warthogs. The swine are remarkable for their wide distribution throughout the world; in fact, they are found everywhere except in the very cold regions of the Earth.

Reconstructing and following the migrations of the many and varied families of Suiformes are difficult tasks; suffice it to say that these animals were found practically everywhere. *Propalaeochoerus*, the ancestor of many families of Suiformes, lived in Europe, while *Perchoerus* was distributed throughout North America and was the probable ancestor of the peccary (Illustration 1a), which is very common today, especially in Central and South America.

The wild boar (Illustration 1b) is presently found in various parts of Europe, but not in its former numbers. These animals have certain features in common with th nct entelodonts, such as size, general proportion of forelegs to hind legs, and A variant of the European wild boar, th hog (Illustration 1c), is found in Africa other variants live in central and soutl ia and in the islands of the Far East

Why have the modern swi planted the ancient entelodonts? This qu perfectly justified in light of the fact tl two forms were remarkably similar. The lies in the size of the brain. Casts of skul ntelodonts show that these animals had nall brains and must have been conside ess intelligent than the other swine fore, they were at a distinct disadvanta e Tertiary world, in which intelligence w oming the dominant factor in evolution

a

b

c

2

THE LONG [illegible]Y OF THE GIRAFFIDS— The family [illegible] presently comprises the giraffes and [illegible]pis only. As often happened with [illegible] specialized kinds of animals, the [illegible] of this family occurred with extreme[illegible]y.

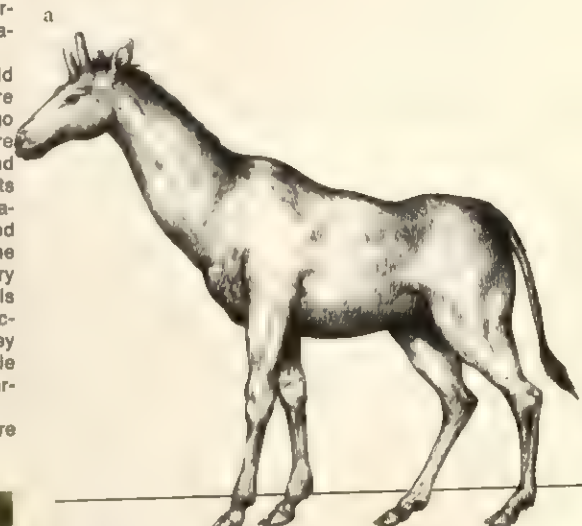
The most [illegible] ancestors of the giraffids date from th[illegible]e and lived in areas along the border [illegible] Europe and Asia. During the Miocen[illegible]rms evolved in two directions: one e[illegible]pidly toward the development of th[illegible] the other retained much its same fo[illegible]ome the okapi. The Sivatherida, an[illegible]g group of animals that was widely [illegible]ed in the Pliocene and that became ext[illegible]ng the Pleistocene, may have been [illegible]h of the original family. *Sivatherium* [illegible]aracterized by a stubby body, a sho[illegible] short legs, and—its most distinguishi[illegible]re—two pairs of horns, of which t[illegible] pair often branched like antlers. Be[illegible]n the Pliocene, the Sivatherida sp[illegible] Asia to North America; during the [illegible]ene, they spread as far south as t[illegible] However, these animals did not sta[illegible] ground so well as certain other grou[illegible] they died out sometime in the Quaternary, both in Africa and in the lands of their origin.

Paleotragus (illustration 2a) was one of the earlier forms of giraffe; its body was stumpier than that of the giraffe, and its neck and legs were shorter. It was common in Asia and North Africa until Pliocene times, when it was supplanted by more specialized forms. In appearance it resembled the modern okapi (illustration 2b).

The similarity between this primitive giraffid and the okapis is interesting. The latter were discovered in the tropical forest of the Congo at the turn of the century. Presently they are distributed there over a very small area, and they are so few in number that conservationists fear the species may become extinct. Migrations of the okapis were much more limited than the migrations of kindred species. The area from which they began to diffuse was very small initially, and these shy nocturnal animals did not wander far. In fact, they probably occupied the same restricted areas where they live today. This phenomenon is remarkable when compared with the migrations that carried certain animals all over the world.

Present-day giraffes (illustration 2c) are characterized by short, skin-covered, furry horns, extremely long legs, and an unusually long neck. The side digits of the hooves have disappeared. Giraffes, which grow to a height exceeding 5.5 m (about 18 ft), usually browse on trees in the savannahs of Africa. Okapis, on the other hand, are much smaller giraffids, rarely exceeding a height of 1.5 m (about 5 ft) at the shoulder, and their necks are much shorter than those of giraffes. Okapis are strictly forest animals.

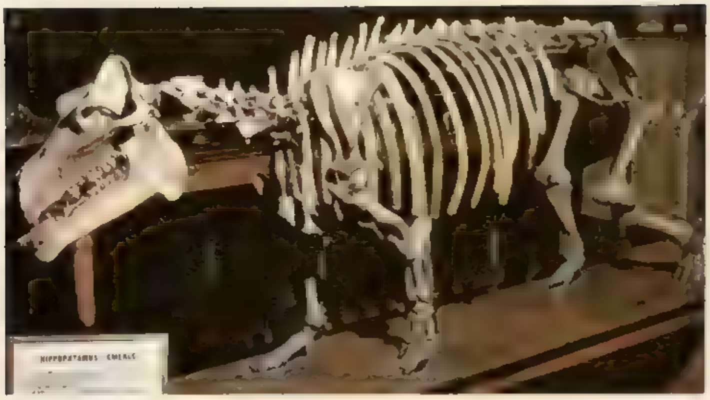
a



b

c

a



b

3

THE HIPPOPOTAMUS—The hippopotamus is a kind of living fossil, at least in some of its features. For one thing, it is something of a rarity among the artiodactyls in the matter of size. Many primitive artiodactyls were as large as the hippopotamus, but they became extinct. The hippopotamus has been able to retain its great size and still survive because it lives a semiaquatic existence; the buoyancy of the water helps this animal support its great bulk.

The digits of the hippopotamus foot are very open and the claws are short. In this animal, the side digits, which are more or less atrophied in nearly all modern artiodactyls, are as important as the middle digits

The skull is a mixture of primitive and extremely modern features. The teeth are highly specialized, as are the dimensions, shape, and strength of the jaw. On the other hand, the brain is comparatively small, at least in comparison with those living art… …yls that can in any way compete with the… …potamus in size

The skeleton of *Hippopota… lemerlei* (Illustration 3a) came from Plio… deposits in Madagascar. This primitive … nal was of about the same size as the m… hippopotamus (Illustration 3b), and the p… …rtions of its body to the length of its legs … …e about the same, although the skull was … …ller.

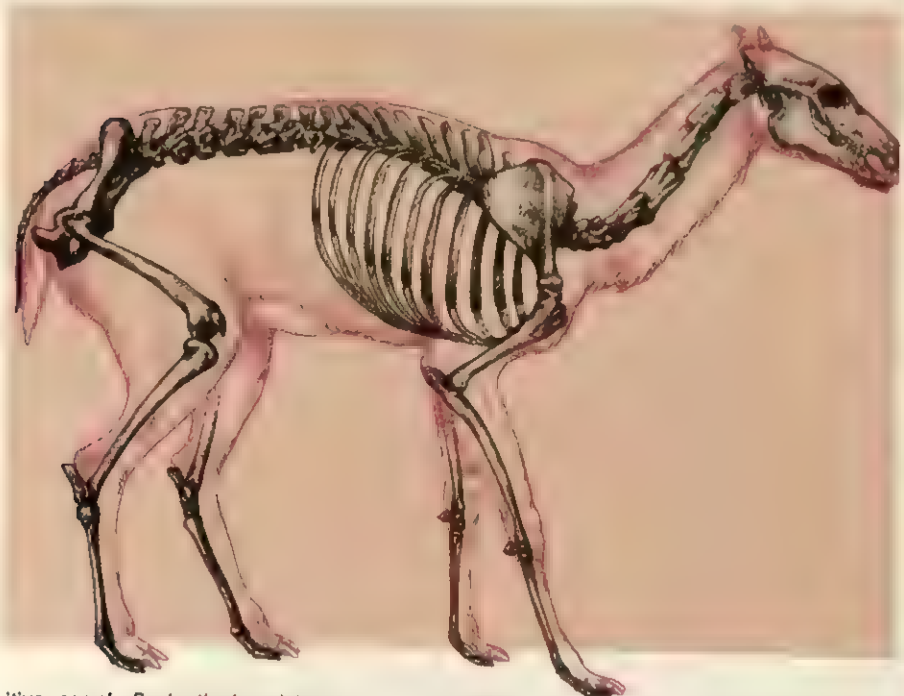
4

THE CAMEL FAMILY—Camels comprise another interesting family of artiodactyls of the Tertiary era and the present day. Today the family Camelidae embraces two genera, *Camelus* and *Lama;* the former consists of two species of camels (the single-humped dromedary or Arabian camel and the two-humped Bactrian camel), while the latter includes the llamas and their smaller relatives, the alpacas, guanacos, and vicuñas.

The camel family has been the subject of a great deal of study. Although very few primitive forms existed, numerous genera evolved from them toward the end of the Tertiary and achieved a wide distribution. Paleontologists experience difficulty in tracing the exact outlines of this distribution and determining how many and which specie… …ere present, and how they migrated. Scien… now believe that camels originated in Nort… …erica about 40 million years ago and sub… …ntly spread to Asia and South America, af… …aving undergone most of their evolutiona… …evelopment.

Illustration 4a is a reconstr… …n of a primitive camel, *Poebrotherium labiatum*, of the Oligocene epoch, which in outward appearance bore little resemblance to the modern camel. It did exhibit the curvature of the spine, the shape of the skull, and the teeth characteristic of the camel. Moreover, it was somewhat reminiscent of the present-day llama. It was a small animal, scarcely bigger than a calf, standing about 1 m (about 3 ft) high.

a



b

At certain points in their development, the camels evolved some forms similar to those of gazelles and other forms similar to those of giraffes. *Stenomylus* was typical of the gazelle-like camels of the Miocene and Early Pliocene epochs. *Alticamelus* (Illustration 4b), which lived during the same epochs, exemplified the very tall camels. This animal stood about 3 m (about 10 ft) high and had a very long neck and very long legs, both reminiscent of the giraffe; moreover, like the giraffe, it browsed on the leaves of trees. In shape and size it differed from the modern camel.

Present-day representatives of the camel family range in size from large to small. The dromedary or Arabian camel is a large animal, measuring about 2 m (about 7 ft) at the shoulder. The llama and its allies are considerably smaller, however. The smallest is the vicuña, which measures about 0.8 m (about 2.5 ft) at the shoulder and reaches a length of about 1.5 m (about 5 ft).

THE PLIOCENE EPOCH | the Earth at the end of the Tertiary epoch

1

← **FOSSILS OF THE PLIOCENE**—This fossiliferous sandstone contains the remains of several mollusk shells (Illustration 1). The pelecypods and gastropods were particularly widespread during the Pliocene epoch.

The last epoch of the Tertiary period, the Pliocene, began about 10 million years ago and lasted for almost eight million years. By the end of this epoch, all the general characteristics of the flora and fauna were completely delineated. The flora, for example, consisted of genera almost identical with those of the present day; Pliocene flora differed from modern flora only in spe ies and in geographic distribution. Th fauna at the end of the Tertiary varie mewhat from present-day fauna, espe lly the higher animals. Rapid evoluti changes occurred among the man particularly among the artiodactyl erissodactyls,

2

THE PLIOCENE WORLD—By the end of the Pliocene, the continents had assumed their present-day features; only minimal differences existed between the contours of the major landmasses in Pliocene times (shaded in dark green on the map) and the present-day contours (black line), shown in Illustration 2.

The outline of the Gulf of California was practically the same as it is today. Around the Gulf of Mexico, however, all that part of the plain that subsequently would be constructed by the Mississippi River and other great streams was still lacking in Pliocene times; this activity was not completed until the Quaternary, when the glacial moraines were destroyed and sediments about 15 km (about 9 mi) thick were deposited in the Gulf of Mexico.

In South America, a large gulf occupied the region where the present city of Mar del Plata now stands. In time, of course, this region was gradually filled through sedimentary processes, unaided by glacial activity.

The contours of Pliocene Africa were not substantially different from the contours of modern Africa. On the Asian continent, however, the continental shelves were exposed by a marine regression. For this reason, the coasts of Indonesia, China, and Korea extended into the ocean. Volcanoes and geosynclines, marine trenches and mountain chains—all were perfectly delineated. The mountains, of course, lacked the incisions that would later be produced by the glaciations of the Quaternary period.

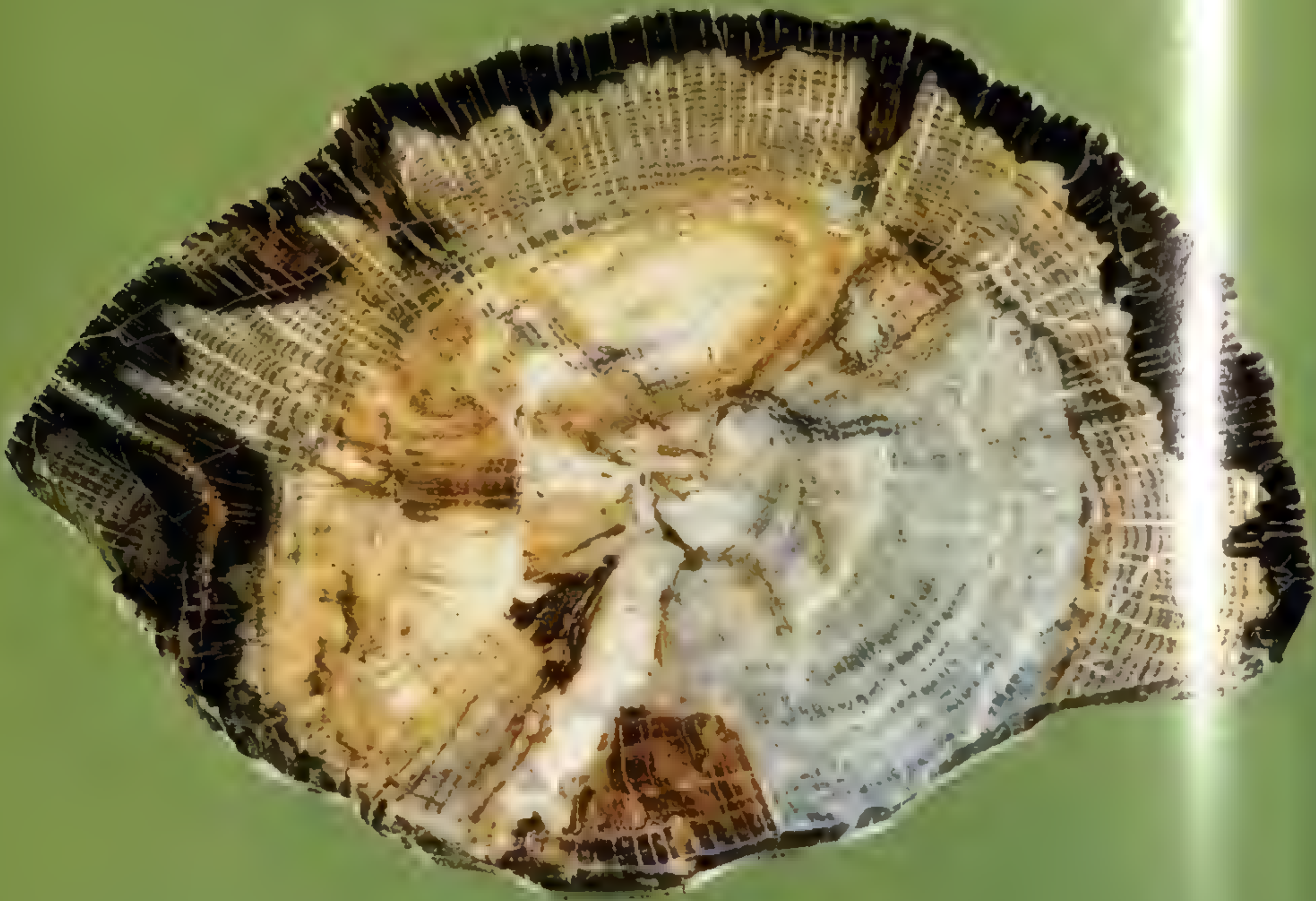
In consonance with the regression of the seas, the Persian Gulf emerged, as did Australia. The Baltic Sea was completely dry, because its floor lay above the average level of the sea; for this reason, England and Ireland were united.

A completely different and historically interesting situation prevailed in Europe and the Near East. The Mediterranean Sea had almost its present shape, although the entire region of the Balearic Islands was joined to the mainland. A land bridge joining the Peloponnesus to Turkey closed the Aegean to form a small lake. With the closing of the Dardanelles, the Black Sea was also isolated. This sea was much larger than it had previously been and was scarcely separated from the Caspian Sea. The Caspian was separated from the Tethys, to which it had formerly been joined, but it was still quite extended and was united with the present Lake Aral to form the Aral-Caspian depression.

carnivores, an[illegible] [illegible]imates. The principal determining [illegible] of evolution became intelligence [illegible]undity.

Interesting [illegible]lopments occurred in geology and [illegible]orphology. In many regions of E[illegible] the sea carried out a complete sed[illegible]ary cycle. In fact, it rose to cov[illegible] terrestrial regions, depositing a thick layer of sediments on them before subsiding to complete the sedimentary cycle. Following the sedimentation of the Pliocene epoch, the sediments were consolidated into rocks and the rocks were thrust upward out of the water. The Pliocene, therefore, was not an epoch of orogenic calm. The Alps and Apennines experienced further upheaval. The occurrence of orogeny in Europe is also indicated by the presence of numerous volcanoes, both in France and in Italy. In North America, some of the volcanoes created during the Miocene epoch continued to erupt during the Pliocene time.

FLORA AND FAUNA OF THE PLIOCENE | some biological developments



SYMBOL OF A TEMPERATE CLIMATE—This section of a silicified oak trunk reveals a structure identical with that of a modern oak. Oaks were abundant throughout the Tertiary and Quaternary periods. These large-leafed plants thrive in climates that are sufficiently humid but not excessively hot. They are found throughout Europe, Asia, and North America.

During the P[illegible]ne epoch, the Earth was subjecte[illegible] gradual decrease in temperature, [illegible]panied in certain regions by a d[illegible]tion of rainfall. This situation was [illegible] contradictory, inasmuch as a [illegible] in temperature ordinarily is a[illegible]anied by an increase in precipitati[illegible]uring the Quaternary period, which [illegible]ediately followed the Pliocene, a t[illegible]dous decline in temperature led [illegible] formation of extensive glaciers; how[illegible] the climatic changes of the Plioce[illegible]e not so great as those of the Quat[illegible]y. Indeed, they were slow and gra[illegible] as they had been during the Pale[illegible] epoch at the beginning of the [illegible]

Pliocene [illegible]ls were highly specialized organis[illegible]d their extraordinary specialization [illegible] the precise cause of their unusu[illegible]pid development. On the other h[illegible] substantial modifications occur[illegible]ong the aquatic animals, espec[illegible]se of the lower orders. The foramin[illegible]rachiopods, and pelecypods, for [illegible], were almost identical with p[illegible]day forms of these organisms. An[illegible]hese lower animals, the fauna of th[illegible]nt day differs from that of the Plio[illegible]ly by the presence of a few species [illegible]have appeared since the end of the [illegible]ry period.

The clim[illegible]hanges of the Pliocene were suffic[illegible] provoke significant migrations of [illegible]ain mammals into areas where they h[illegible] not previously lived. As a result of these changes in habitat, the mammals were subjected to a vigorous process of natural selection. Two factors were important to survival in the new habitats. First, the new species had to adapt to the food supply available in the new environment. Second, they had to be able to resist or prevent the destruction of the species by the already large group of carnivorous predators that had spread to all parts of the globe, adapting themselves to both very hot and very cold climates.

Some distinctive changes occurred among the higher mammals. For example, the Pliocene was marked by the appearance of the first horse (*Pliohippus*) with a single, highly developed nail and clearly atrophied lateral digits; this hoof was quite similar to the hoof of a modern horse.

Another phenomenon of great importance was the appearance in Asia, and particularly in India, of the bovines—a buffalo and an ox, both with broad foreheads. The deer appeared in Europe, where they stabilized quickly and differentiated into an enormous number of species.

The Pliocene was also distinguished by great developments among the carnivores, both large and small. Of the relatively small carnivores, the lynx survived both the Pliocene and the subsequent Quaternary and exists today as a modest-sized cat with strong predatory habits.

Larger felines also lived during the Pliocene. The lion and the panther looked much as they do today, but machairodonts (saber-tooth cats or tigers) differed considerably from animals living today. The latter survived until the Late Pleistocene and were formidable predators with highly specialized teeth. The upper canines attained considerable length and protruded outside the mouth.

Another noteworthy phenomenon of the Pliocene marked the end of the isolation of the South American continent. The narrow isthmus of land that still connects North and South America emerged from the sea and provided an avenue for migration from one continent to the other. The deer and camellike animals (llamas) then spread by way of this land bridge from North America to South America, where today they are characteristic mammals. In what is now Texas, the first appearance of large ground sloths (*Megalonyx*), migrants from South America, also resulted from the connection between the two continents.

Despite the general similarity between the fauna of the Pliocene and that of today, certain animals that could be described as monsters existed near the end of the Tertiary period. Huge mammals of the order Proboscidea (elephants) also thrived during the Pliocene epoch. They included the *Dinotherium*, with recurved lower jaw tusks; *Stegodon*, ancestral elephant; and *Mastodon*.

Among the primates of the Pliocene were the monkeys *Macacus* and *Cercopithecus* and the apes *Dryopithecus* and *Pliopithecus* in Europe and a larger number of genera in Asia.

Finally, developments occurring among the primates would lead to the eventual appearance of man. No one knows exactly when and where man appeared; however, near the end of the Pliocene or early in the Pleistocene, primitive hominids appeared on the scene. These animals, pithecanthropids and australopithecines, possessed forms truly intermediate between those of apes and men. Having already acquired a vertical or almost vertical posture, these hominids walked upright on their hind legs. In addition, some primates of the Pliocene, particularly the baboons, apparently hunted other primates, preying on smaller monkeys. The cranial capacity of the baboon, already 600 to 900 c^3, was less than that of the hominids, but it was still larger than the cranial capacity of every other species of monkey then alive.

Little needs to be said of the Pliocene flora except that it was remarkably similar to the flora of the present day. Unusual, however, was the flora of England, which was dominated by a mixture of Japanese and North American forms with some Himalayan and Indo-Malayan types. Lower temperature and rainfall at the close of the Eocene epoch resulted in a gradual movement of vegetation southward, although subtropical and warm temperate trees and shrubs lingered on into Miocene and Pliocene time along the westward shores of the continents, especially in Europe. Unlike the north-south ranges in North and Central America, which permitted migration to more favorable latitudes, the transverse Alps served as a barrier to southward movement into Africa, as did the Tethys-Mediterranean waters.

In the western hemisphere, the Pliocene flora from high altitudes in Bolivia included plants whose living relatives occupy lower regions with higher rainfall and temperature; it is thought that this part of the Andes has been uplifted about 1,500 m (about 5,000 ft) or more in post-Pliocene time. In North America, several kinds of deciduous trees, such as the beech, chestnut, oak, elm, and hickory disappeared from the West during the Pliocene and have survived on that continent only in the East, where a wet summer climate has persisted. The redwood (*Sequoia*) became restricted to the immediate borders of the Pacific Ocean. It became extinct in Eurasia before the end of the Pliocene epoch.

THE ROLE OF INTELLIGENCE | evolution of nervous systems

Of all the members of the Animal Kingdom, the mammals in general and the primates in particular are endowed with the highest levels of intelligence. In large measure, this factor accounts for the success of these animals.

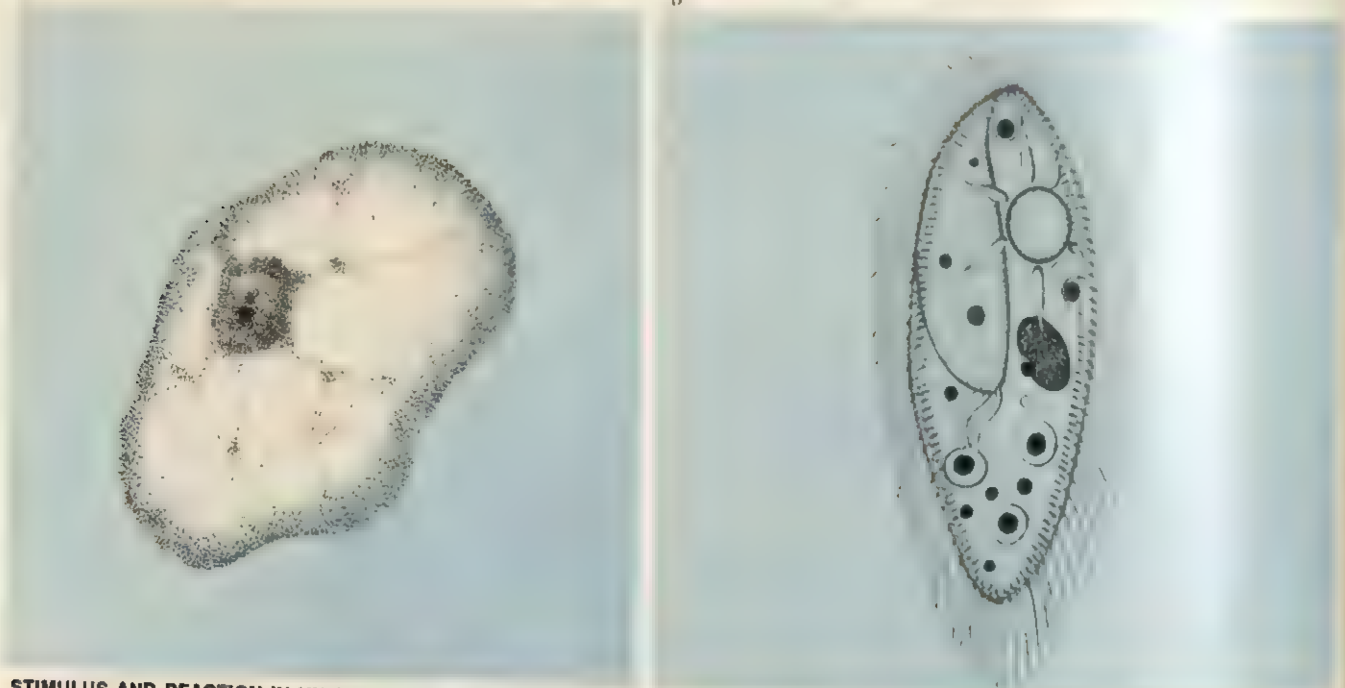
The monkeys of the Miocene epoch had a level of intelligence never before possessed by any animals. Intelligence was not a new characteristic, of course, for all the higher animals of the Miocene world already possessed intelligence to a greater or lesser extent. Nevertheless, the role of intelligence became increasingly important during the subsequent epochs, especially during the Pleistocene and Recent epochs of the Quaternary period. Developments in the animal world were increasingly determined by the possession of intellectual faculties rather than by the usual physiological adaptations to the environment.

The intellectual hierarchy within the primate order has not been fully established beyond placement of man at the top. Chimpanzees appear to be superior to other apes, although the abilities of orangutans and gorillas have not been explored as thorough [illegible] bus monkeys approach chimpanzee [illegible] mastering motor skills and using too [illegible] ut they are inferior in most learnin [illegible] to chimpanzees, macaques, and [illegible] monkeys.

The development [illegible] igence in the higher animals is such [illegible] mportant subject that it warrants [illegible] te study. As a background to this st [illegible] knowledge of the development [illegible] nervous systems in lower anim [illegible] invaluable Therefore, the emph [illegible] re is placed on the origins and dev [illegible] ents of these systems.

1

a b

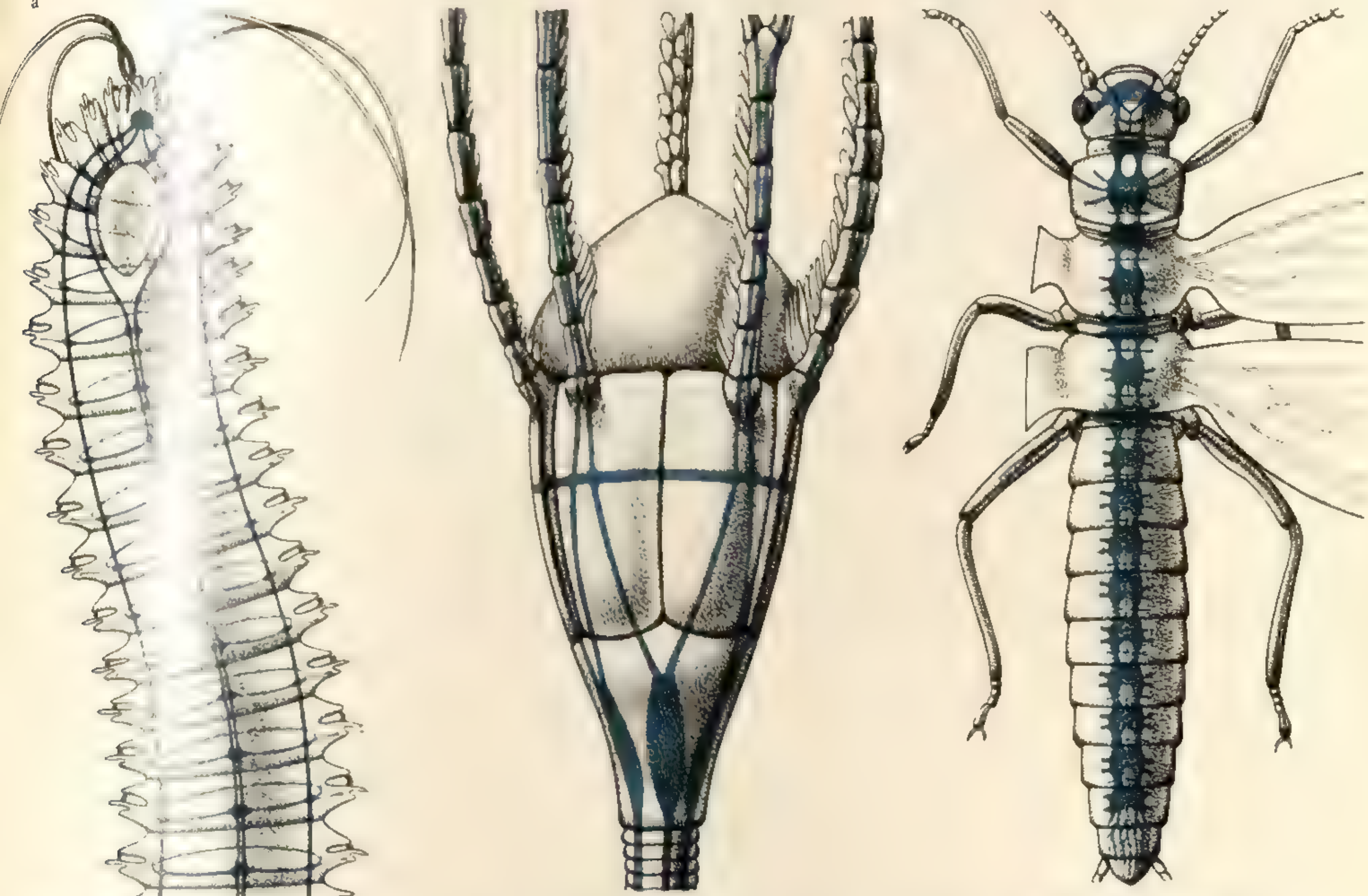


STIMULUS AND REACTION IN UNICELLULAR ORGANISMS—A unicellular organism by its very nature is simple in structure, yet the material comprising the organism is highly organized at the molecular level. The unicellular organism does not possess organs in the usual sense; however, the cellular matter is organized into specialized parts, called organelles, that serve different functions. The organelles, because of their specialized functions, react according to certain patterns in response to the diffusion of chemical substances throughout the cell. For example, the presence of a certain substance diffusing through the cellular material serves as a stimulus, which in turn produces a reaction.

The simplest, most primitive type of unicellular organism (illustration 1a) is at the mercy of its environment. It must wait until nutrients pass from the exterior environment through the cell membrane into the interior. It cannot initiate action to acquire food; it merely responds or reacts to the stimuli acting on it.

A single-celled ciliate such as *Paramecium* (illustration 1b) also has a very simple structure, but it is capable of moving under its own power. This organism has a simple system of stimuli-conducting fibers connected with the cilia, which resemble tiny hairs. The oarlike movements of the cilia vary in intensity as these organelles react to chemical stimuli. The coordination of ciliary movements suggests a primitive form of nervous control.

2



SENSORY CELLS AND PRIMITIVE NERVOUS SYSTEMS—Organisms perceive and relate to their environments through various senses. The stimulation of a sense organ by a particular stimulus—such as light, heat, sound waves, or chemical substances—causes signals to be transmitted through a network or system of nerves. Sense organs probably originated before nervous systems, as such, evolved. In fact, the earliest appearance of a sense organ dates back perhaps to Precambrian times, more than 550 million years ago.

Of the lower animals now living, the flatworms known as planarians possess the most primitive sense organs. These are light-sensitive cells that enable the animal to distinguish between light and darkness. Planarians also possess certain structures that enable them to sense the presence of food in the environment.

The annelid or segmented worm (Illustration 2a) has a more highly developed nervous system than the planarian, yet it is relatively simple. A nerve cord, situated on the ventral side of the animal, extends the entire length of the body; numerous ganglia branch off the nerve cord, and one large ganglion in the anterior region of the body functions as a kind of brain.

A primitive animal such as the crinoid (Illustration 2b) has a relatively well-developed nervous system. It consists of a nerve ring that encircles the digestive apparatus and from which the radial nerves branch off. The stimulation of sensory cells, which are distributed along the body, causes signals to be transmitted through the nervous system, thereby provoking a reaction at a certain point in the crinoid structure—such as the contraction of a muscle and the consequent closing of the mouth. Although the crinoid nervous system is rather primitive, it involves some very precise activities.

In these primitive nervous systems, the transmission of information is an elementary function that does not involve true correlation of data. The animal does not decide what it must do in a given circumstance, but it reacts automatically and in predetermined patterns to specific stimuli.

One function of memory exists, however, despite the lack of a memory mechanism. In fact, the stimulus-reaction concatenation is already a predetermined pattern and is thus the implantation of something to remember. Even in very primitive animals, the insects, elementary functions of memory are evident. The structure of an insect (Illustration 2c) is still ganglionic, but already very complex, permitting a high level of psychic activity. This animal is capable of moving itself and selecting and using food. The fact that the insect has a predilection for certain flavors or colors is based on an innate behavior pattern.

3

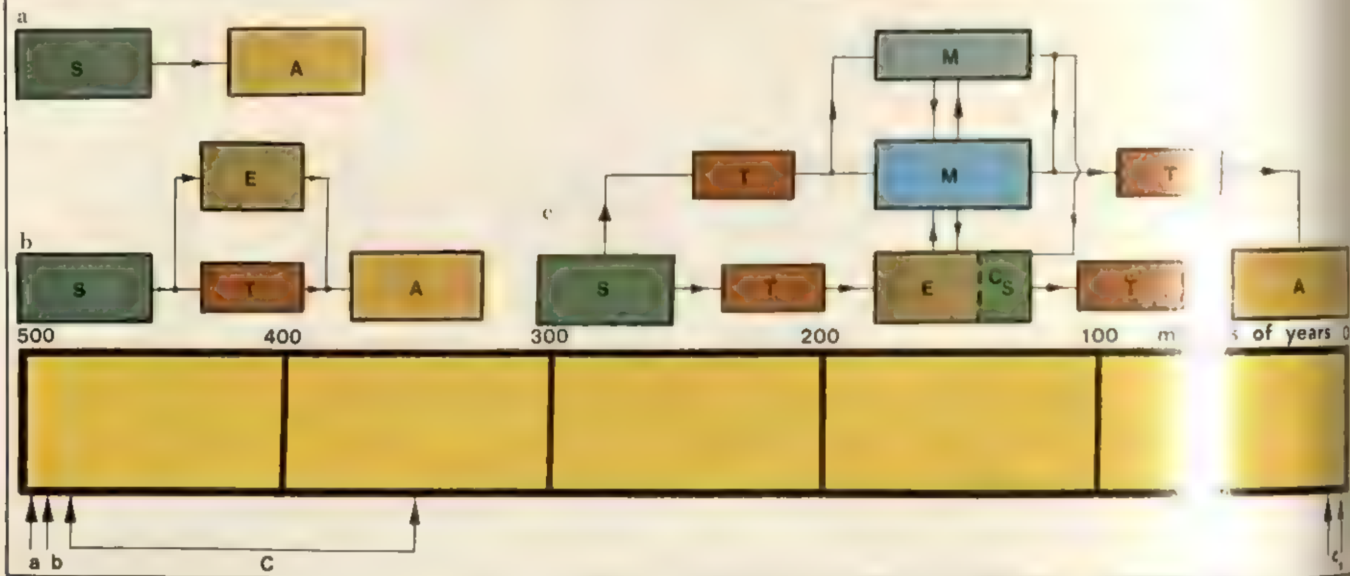
THREE STAGES OF DEVELOPMENT—The development of a nervous system may be considered to have occurred in three stages.

The first stage (Illustration 3a) was marked by the presence of a sensory cell **S** inside the animal and connected with whatever mechanism carried out the reaction to the sensory stimulus **A.** Scientists have no way of knowing when this type of organ originated, but they estimate that it first appeared between a half billion and a billion years ago.

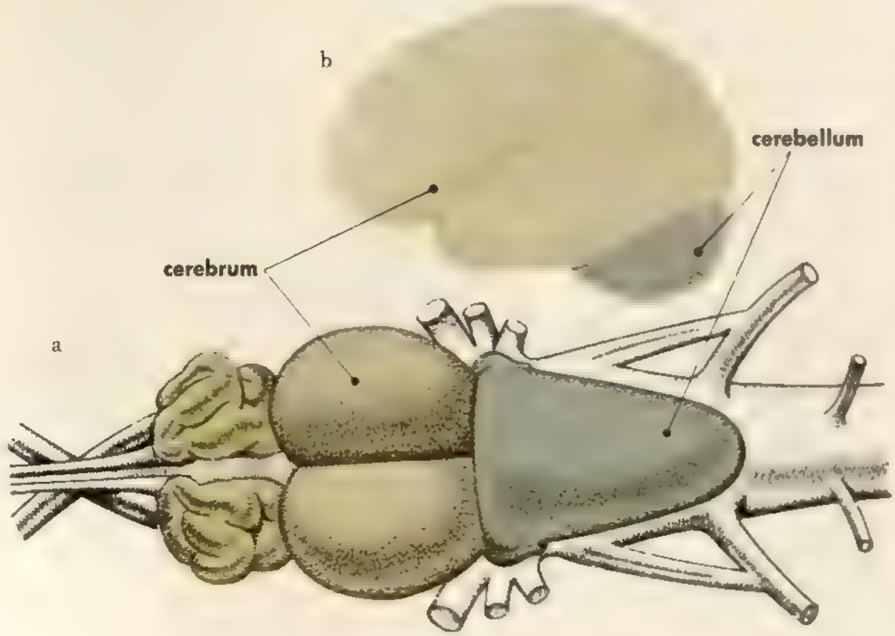
In the second stage (Illustration 3b), the system became more complex in that the stimulus was elaborated before producing the reaction. The mechanism for the elaboration of information **E,** together with the mechanism for transmission **T,** dates back to the appearance of the mollusks, presumably in Precambrian times.

In those higher animals that are inferior to the chordates, the nervous system became remarkably complex (Illustration 3c). The sensory cells transmitted information (signals) to an elaborating mechanism and to a memory mechanism. The memory mechanism was divided into two parts: one part served to collect information from the experience of the senses **M,** while the other part contained hereditary information **M'.**

The time line (Illustration ... ndicates when the various stages in the ... opment of the nervous system presumat ... ginated. Obviously the dates are vague ... use fossils for this research, especially ... related to the first phase of developme ... not presently available. The most adv ... unctions, indicated in Illustration 3c by ... etters **C_s**, may be defined as the elal ... of strategy. These functions appeare ... e end of the Tertiary period, although ... forms of them undoubtedly appeared m ... rlier.



4



A FOSSIL IN THE HUMA... DY—The function of a primitive nervou... m was to provide automatic response... timuli. Higher animals also have need of ... nisms to provide automatic responses ... the regulation of the heartbeat and the ... thing rate. In human beings, the portion ... nervous system that controls these acti... has remained separate from the part that p... des the higher functions. The cerebellum, th... erefore, may be considered a kind of foss... e human body that serves the type of functi... characteristic of primitive organisms. In the human being, nevertheless, even the most elementary functions have become so complex that the control organ (brain) has become fairly large.

At a certain point in the history of evolution memory and elaboration mechanisms became concentrated in one part of the nervous system, where they acquired a compact form: the brain. In fact, from the moment when either the sense organs or the motor organs became scattered throughout the body, the nervous functions had to be grouped together in a single decision-making unit.

Although still primitive, the brain of a fish (Illustration 4a) is a highly developed organ but it is much inferior in development to the brain of a Tertiary mammal or that of a man (Illustration 4b).

THE QUATERNARY PERIOD | the last two million years of Earth history

The second n[illegible] ivision of the Cenozoic era is the Q[illegible] ary period, which began a little [illegible] wo million years ago and continu[illegible] the present day. Compared with p[illegible] periods, the Quaternary covers [illegible] short span of time. In fact, some g[illegible] ts consider the period as a mere [illegible] n or continuation of the Tertiary [illegible] scientists, however, feel justified [illegible] garding this period as distinct fro[illegible] rest of the Cenozoic, because it w[illegible] tinguished by tremendous climati[illegible] ges and by the emergence of ma[illegible] e master of the Earth.

The Quat[illegible] period has been characterized by [illegible] sive glaciations, which brought ab[illegible] true revolution in the geomorphol[illegible] f the continents. Tremendous i[illegible] ts were formed, not only in the [illegible] tainous regions of the world, but [illegible] areas that were nearly flat at the b[illegible] ning of the period. The tropical cl[illegible] s of certain regions checked or [illegible] tly prevented the formation of glac[illegible] n those regions.

The biolo[illegible] phenomena that usually help to defi[illegible] e boundaries of periods were also v[illegible] closely linked with the glacial acti[illegible] of the Quaternary. The colossal tran[illegible] mations in the flora and fauna were [illegible] duced chiefly by the alternation of ex[illegible] tionally cold periods with very warm or even subtropical periods. These climatic variations undoubtedly had great influence on the evolution of mammals and men, because they impelled many species to migrate across entire continents in a relatively short span of time.

Whereas the limits of preceding eras and periods have been established by major marine transgressions and regressions, the Quaternary was distinguished by a tremendous regression of the sea, which resulted from the accumulation of water on the continents in the form of ice sheets. For this reason, most of the continental shelves were uncovered, and the deposition of marine sediments in these areas ceased completely.

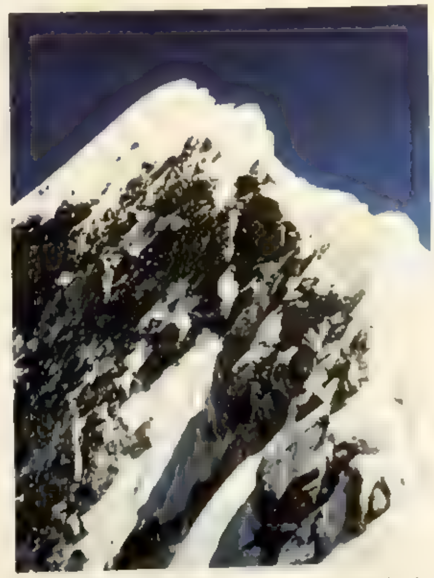
On the other hand, extensive continental deposits were formed. Many of them have distinctive characteristics arising in part from the manner in which they were formed and in part from the fact that, being geologically recent, they have had very little time in which to be consolidated and metamorphosed. Glacial moraines constitute the most important continental deposits of the Quaternary, but deposits of a fluvial nature were also formed in areas unaffected by glaciation. Among other characteristic deposits of the continental type are those that originated during a glacial phenomenon and subsequently underwent radical changes. Such transformations have occurred among the deposits that the enormous North American glaciers drove before them, tearing them away from the regions that they originally covered and pushing them great distances southward.

The deposits of Chinese loess came from dust transported by glaciers; in successive phases of withdrawal, this dust was deposited on the ground and carried by the wind far from its original location.

THE PHENOMENON OF GLACIATION

Geologically speaking, the principal events of the Quaternary period were the glaciations, which deserve considerable attention because they have practically sculpted the Earth, giving it its present relief. First of all, the glaciers leveled continents that had little relief or were almost entirely flat. Second, they caused the accumulation of enormous amounts of detritus, which covered vast plains and even filled the basins of seas. The Po Valley in Italy, for example, was formed entirely during the Quaternary, as the colossal glaciers of the Alps and part of the Apennines transported huge quantities of morainal detritus to the valley and deposited this material in the Po Sea.

The exact cause of the Quaternary glaciations is unknown. Some scientists hold that they resulted from some astronomical phenomenon, such as the movement of the Earth away from the sun. Others contend that the glacial episodes were produced by strictly meteorological or climatic factors. In any case, four periods of glaciation occurred, and each exerted great influence in modifying the flora and fauna of certain parts of the world, notably Europe, northern Asia, and North America.



CONTINUING HISTORY—This lofty peak in the Himalayas originated during the Tertiary period, but it is still in a phase of uplift. At least for the moment, therefore, the young forms of the Himalayan relief are not destined to age, because continuous uplift keeps them young.

Some of the great orogenic or mountain-building activities of the Tertiary have completely halted. Others, after an almost definitive halt, have resumed. For example, some sedimentary deposits at the foot of the Alps, dating from the end of the Pliocene, have risen again, producing a rejuvenated external structure.

Many Himalayan valley forms are similar to those in the Alps and other mountain ranges that were eroded by glaciations following orogeny.

SUBDIVISION OF THE QUATERNARY

The Quaternary has been divided into two epochs only: the Pleistocene and the Holocene or Recent. The Pleistocene is by far the longer of the two, covering all but the last 11,000 years or so; it is frequently called the Great Ice Age or the Glacial epoch, because of the enormous glaciations that distinguish it. Obviously, from a climatic point of view, the Quaternary is completely separate and distinct from the Tertiary period; however, from an orogenic point of view, the

QUATERNARY FORESTS—This photograph of the Black Forest in Germany suggests how Europe must have looked at the end of the last episode of glaciation. The advent of the glacial ages and the subsequent interludes of warmth evoked profound changes in the flora. The ages between the glaciations were always relatively hot, but in central Europe, these interludes were distinguished by the growth of conifers and other plants typical of cold or cool climates. By the end of the fourth glaciation, central Europe was covered by a vast forest that was still intact when Julius Caesar crossed the Alps and invaded Germany. The forest remained, in fact, until about A.D. 1700, when it began to be reduced by cultivation.

Tertiary and Quaternary are closely linked. All over the world, but especially in the Alps and the Himalayas, orogeny proceeded undisturbed from the latter part of the Tertiary into the Pleistocene. Both the Alps and Himalayas underwent considerable deformation as a result of folding and thrust faulting. In western North America, orogenic activity also continued into the Pleistocene. Earthquakes of tectonic origin indicate that orogeny continues in the present day.

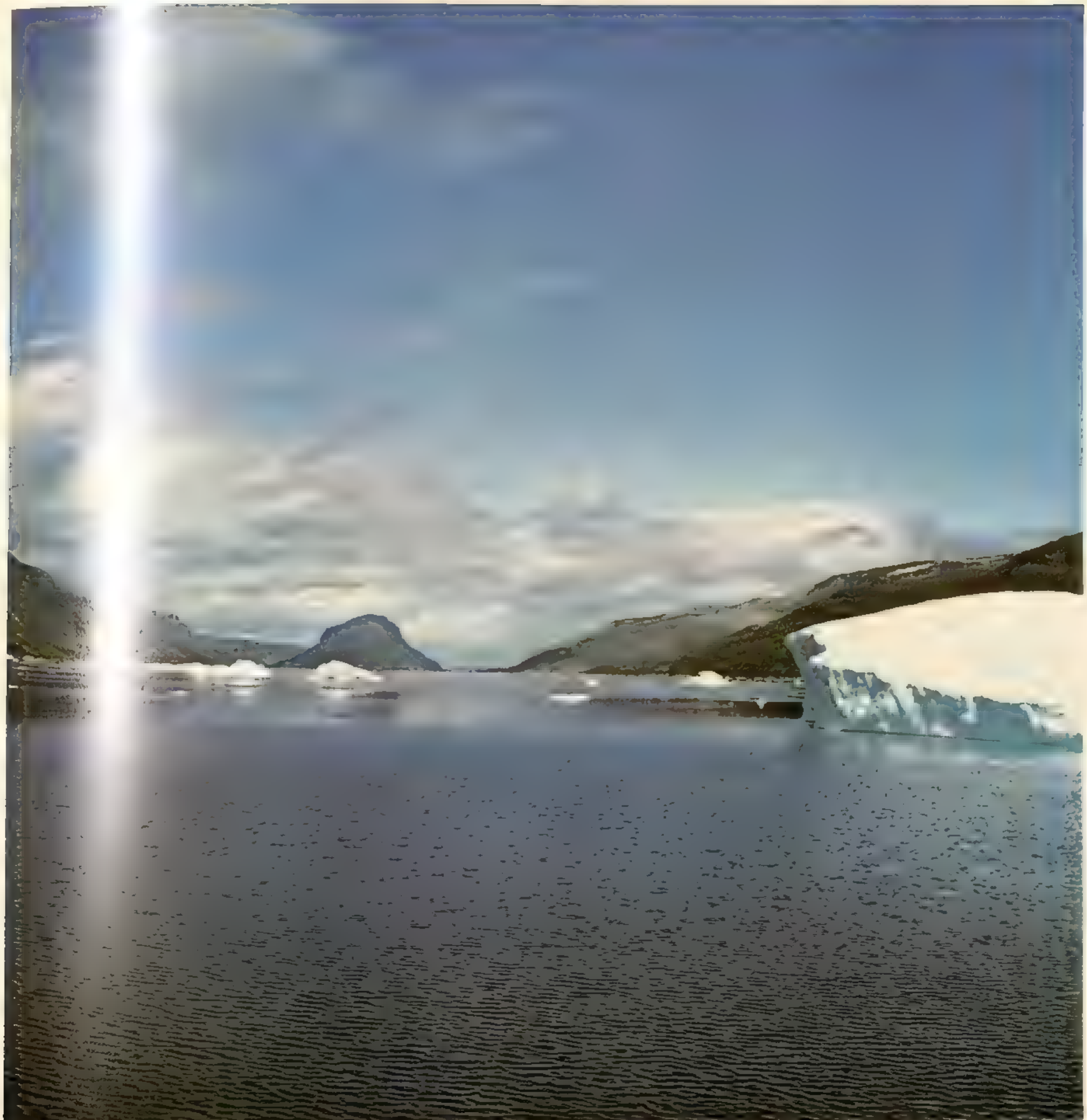
In a certain sense, magmatic or igneous activity during the Quaternary may be considered a direct continuation of phenomena begun in the Tertiary. For example, two important volcanic systems in Italy (one in Tuscany and the other in Latium-Campania) continue the activity that began in the preceding period. However, in the Veneto region of Italy, Tertiary volcanoes are practically extinct. In contrast, Mount Etna is completely new and of Quaternary origin.

Biologically, the only significant difference between the Pleistocene and the Holocene or Recent epoch lies in the number of species in existence. The Recent epoch (encompassing approximately the last 11,000 years) has been marked by a rapid decline in the numbers of species; unfortunately, although some species have become extinct as a result of natural phenomena, the decrease generally must be attributed to men.

The hominids that appeared around the end of the Tertiary or the beginning of the Quaternary possessed skulls with a capacity of 600 cm^3, about half the average brain size of modern man. By a half million years ago, the cranial capacity had increased to almost 1,300 cm^3, and man had almost manifested some characteristics that foreshadowed the present level of civilization. In any case, civilization began only about 15,000 years ago, with the appearance of agriculture and certain artistic manifestations. In an approximate way, then, the birth of modern civilization practically coincides with the beginning of the Recent epoch.

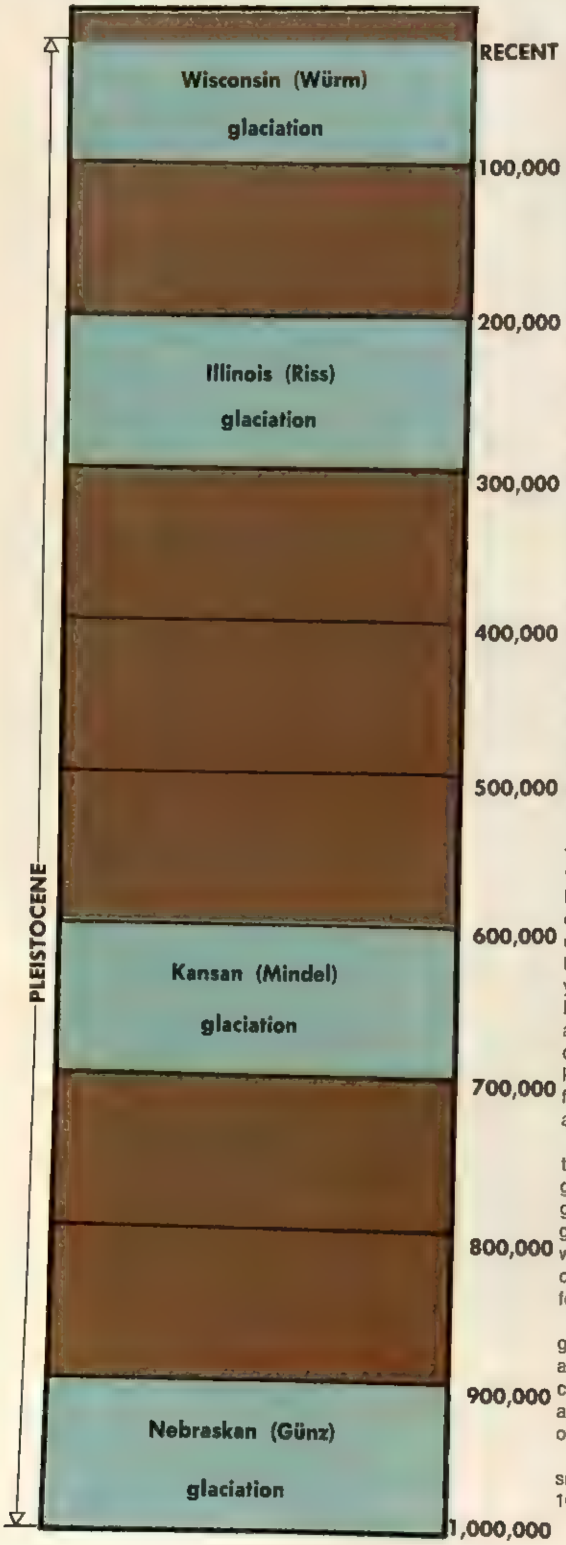
The profiles of the Pliocene continents were relatively different from those of the major landmasses today; during the Pleistocene, some shifting of coastlines occurred as a result of the marine regression, which in turn was produced by the accumulation of water on the continents in the form of glaciers and ice caps. When the ice melted, however, the water flowed back to the sea and the coastlines acquired their present configurations.

The vegetation of the Pleistocene grades almost imperceptibly into that of today. Fossil plants preserved in clays and in peat and asphalt deposits nearly all represent modern species. Their distribution, however, may be different because of the relatively rapid changes in climate that characterized the Pleistocene. The southward extension of continental glaciers in the northern hemisphere took Arctic birch and willow into England during colder and moister stages. The occurrence of white spruce (*Picea glauca*) in Louisiana, more than 1,200 km (about 800 mi) south of its present southern limit, indicates a corresponding glacial climate in North America. On the Pacific coast, where glaciers are not known to have come down from the mountains to the coastal plain, the redwood (*Sequoia*) appears to have lived in the regions that it now occupies; but it also ranged into southern California, where the present warm, dry climate is unsuited to it. Fossil cones of Monterey pine (*Pinus radiata*), Bishop pine (*P. muricata*), and other northern species also indicate a cooler and more humid climate than is found there now. During an interglacial stage of the Pleistocene, Monterey pine ranged north along the Pacific coast beyond its present limits. The sequence of fossil floras in the John Day River basin of eastern Oregon provides one of the most complete known records of plant migrations. It is a region of low rainfall and of wide temperature extremes, with willow, cherry, hackberry, and other small trees largely limited to the river borders. In the Middle Tertiary period, however, the region was inhabited by redwoods like those now living on the humid coast of Northern California.



GLACIERS ON THE CONTINENTAL SHELVES—The formation of ice caps on elevated reliefs has produced typical erosion in glacial valleys, as may be seen today in the valleys of the Alps. Where the land was already flat and near sea level, on the other hand, the land sank into the sea under the weight of the ice—in accordance with the theory of isostasy. The movement of the ice mass did not produce erosion furrows; it simply bared and smoothed the rocks. When the ice melted, the land re-emerged, and its surface, partially bared of its humus covering, may be seen today along the coasts of Canada and Scandinavia.

GLACIAL AGES | subdivisions of the Pleistocene epoch



1
SUBDIVISIONS OF THE QUATERNARY—The Quaternary period of the Cenozoic era is divided into two epochs, the Pleistocene and the Holocene, of which the Holocene is the most recent. The durations of these two epochs are quite different; the entire Quaternary spans some two million years, of which the Holocene or Recent epoch covers about the last 11,000 years—that is, from the last glaciation to the present day. In contrast, the Pleistocene or Glacial epoch has a duration of almost two million years. Strictly speaking, because of its brevity, the Recent cannot be considered a real geological epoch, although interesting events have taken place during its extension in time. From a geological point of view, the Recent cannot be subdivided. The latter half of the Pleistocene, on the other hand, can be subdivided into glacial and interglacial ages. The classification of glacial ages in North America differs from European classifications. In North America, the ages are named for glacial phenomena that have been studied particularly in certain states. In Europe, several classifications are recognized one is concerned with glaciation in the Alps another with glaciation in North Germany and Scandinavia, and still another with glaciation in the British Isles. Mountain glaciation occurred in the region of the Alps, of course, but Scandinavia was characterized by successive movements of a great continental ice sheet. Despite the differences in these types of glaciation, geologists frequently accept the subdivision of the Alpine region as the standard for all of Europe.

Geologists find it difficult to pinpoint in time the exact onset of the first glaciation, because the early part of the Pleistocene was marked by a continuation and intensification of the cooling tendency begun during the Pliocene epoch. Nevertheless, they generally agree that the first glaciation began about one million years ago and lasted for about 100,000 years. In North America, this glaciation is identified as the Nebraskan glacial age, in the classification of the European Alpine region, it is known as the Günz The first glaciation was followed by an interglacial age that lasted about 200,000 years.

About 700,000 years ago, the second glaciation began. This ice age is called the Kansan glacial age in North America and the Mindel glacial age in Europe. The subsequent interglacial age lasted about 300,000 years, during which time worldwide temperature increased considerably, as it always did in the intervals following the glaciations.

The third glaciation, known as the Illinoian glacial age in the North American classification and the Riss glacial age in the European Alpine classification, also lasted about 100,000 years, and was followed by another interglacial age of about 100,000 years' duration.

The most recent glaciation was the Wisconsin or Würm glacial age, which began about 100,000 years ago.

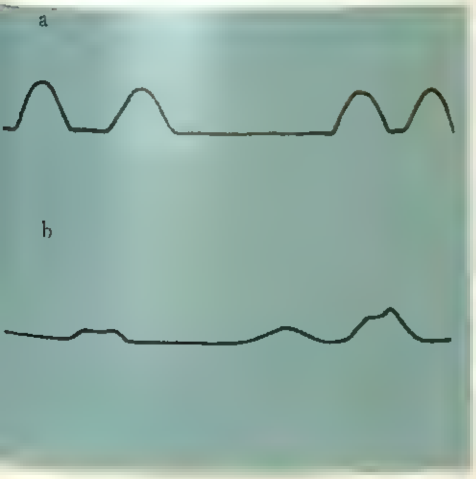
Geological studies co… such a mind-staggering span of … that scientists have divided Earth… …ory into eras, periods, epochs, and … …n the basis of plant and animal life t… …xisted at given times. For the eras … …riods preceding the Quaternary, … …bdivisions are based primarily on … …sis of marine sediments; a marine t… …gression or regression signaled th… …nning or end of a sedimentary ev… …ften this phenomenon was relativ… …ief, compared with the duration of … entire era or period, in which cas… boundary between one time interv… …nd the next is clear-cut. Neverthele… the sedimentary cycles were not … a movement of the sea on a worldw… …scale, the divisions are rather in… …r have only regional significance … …tological stratigraphy helped cons… …y in establishing these subdivisions … …ugh rock may be mineralogically th… …e throughout its fossil content often … …ies.

The Quaternary … presents a completely different s… …ircumstances. This period is charact… by a number of glaciations that p… …d such substantial changes in the… …a, fauna, and geology and left … incontestable traces, that subdivis… …is extremely clear-cut and precise. … …rst glaciation probably began about … million years ago; therefore, the first … …llion years or so of the Pleistocene … …efined principally on the basis of … fauna, which differs in certain ways from that of the preceding epoch, the Pl…cene. The history of glaciations is quite complex, not only because several glaciations occurred, but also because they covered chiefly high reliefs or continental blocks at very high latitudes, rather than the entire surface of the Earth's land areas. The passage from one glacial episode to the following interglacial interval proceeded by fits and starts—the glaciers or ice sheets stopped for a while in their retreats, then continued again, stopped again, and so forth, up to five or ten times for each interglacial phase. Consequently, the history of the construction of glacial morainal sediments is both complex and interesting.

2

CAUSES OF ATION—Even today the causes of glac can merely be theorized. In Greenland ntarctica the conditions for forming co ice sheets result, insofar as is known, t extreme cold. However, the occurrenc Pleistocene glaciations at low latitudes t be attributed to the extremely low t atures found today in the Antarctic or nd. They may have been caused by an nely large amount of precipitation dur winter or throughout the year. The Ant however, where conditions for maintaini extremely thick ice sheet exist, has a nual rainfall, only slightly above that Sahara. In all likelihood, therefore, th limate rather than precipitation determ e accumulation of ice and snow. Many s have suggested that astronomical p na during the Pleistocene might have p d a variation in the amount of solar rad ceived by the Earth and, therefore, a in the overall temperature, with ent accumulation of ice. However, th hesis has not been proved.

The illust ows two climatic curves based on di heories. One theory (Illustration 2a) p s that the four glaciations were of equ nsity; the other (Illustration 2b) holds t first glaciation either did not occur o ery weak. The latter theory is suspect i clear signs of the first glaciation appear e peaks of the highest mountains in the erosion by subsequent glaciations ha been able to destroy this evidence.



3

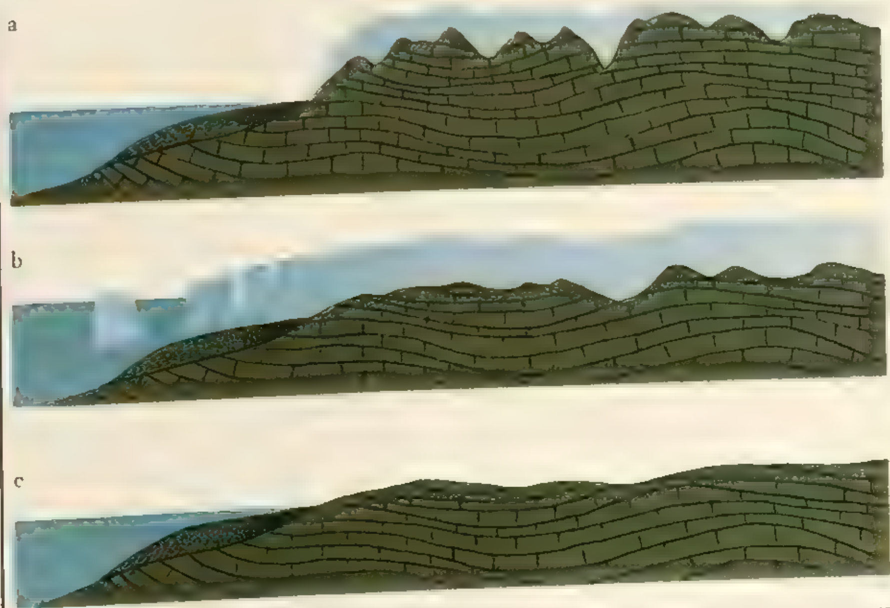
HISTORY OF GLACIATION SCULPTURED IN ROCKS—This photograph shows a glacial valley in the Alps. The glacier dates from the last glaciation, the Wurm, which was less intense than the preceding glaciations. The U shape characteristic of glacially formed valleys is evident; the U formed in the highest part of the valley was produced by the preceding glaciation, the Riss, which was much more widespread than the Würm.

4

GLACIATIONS AND ISOSTASY—This series of illustrations shows what may happen to lands subjected to intense glaciations. Illustration 4a shows a continent or subcontinent emerging from the sea. On the left are the bathyal depths, toward the center are the depths of the continental shelf; and on the right, the emerging lands. An ice cap forms and progressively covers the land. Its weight deforms the Earth's crust and underlying mantle so that the entire continent or subcontinent sinks. Only the highest peaks of the mountains rise above sea level, and they are covered by the tight-fitting ice cap.

Subsequently (Illustration 4b), the ice sheet moves toward the sea and breaks up, producing enormous icebergs. The continuous movement of the ice sheet on the continent over a long period of time erodes and levels the land.

When the ice cap melts, the subcontinent is free of the ice and its weight. According to the theory of isostatic adjustment, the land then rises out of the sea (Illustration 4c). However, its former relief features have been almost entirely eliminated or extremely minimized by erosion. This effect of glaciation can be observed today in the lowlands of northern Canada, Scandinavia, and much of Siberia. Greenland and probably Antarctica are also affected by intense glaciation of this kind.



5

GLACIAL FORMS—These maps illustrate the forms and extensions of various types of glaciers of increasing dimensions. A typical valley glacier (Illustration 5a) forms when snow accumulates on a mountain during the winter, but does not melt completely during the warmer summer months. The accumulated mass of snow and ice becomes compact as it absorbs water from the melting snow on the surface. This mass may then migrate toward lower elevations, where it melts completely under the influence of the higher temperatures. This progression is typical of many small valley glaciers, as well as the larger, present-day Alpine glaciers, particularly those of the southern slopes.

Large glaciers typical of the Himalayas take a somewhat different form (Illustration 5b), with several glacial tongues extending down the mountainsides even to very low elevations.

During the glacial ages of the Pleistocene, the area north of the Alps presented a contrasting picture to that of the south. In the south, the glaciers were separated from one another and generally stopped before reaching the plains. However, north of the Alps (Illustration 5c), the larger glaciers invaded the plains, and their icy tongues fused together. The merger of these glaciers began to cover the regions immediately below the Alps and the central European plains with a solid blanket of ice. This blanket remained almost motionless, because, although it was fed by glaciers moving from the south, it was also melted along its terminal edge by the higher temperatures of the low elevations.

Finally, at higher latitudes, temperatures were so low, even at sea level, that ice caps or ice sheets formed. Ice sheets covered entire continents or subcontinents, often to a great depth, thereby causing them to sink under the weight of the ice. The ice sheet covering Greenland today is estimated to be about 3,350 m (about 11,000 ft) thick; that covering most of Antarctica (Illustration 5d) today may be more than 2,400 m (about 8,000 ft) thick in certain places.

THE HISTORY OF GLACIATIONS

1

← **GLACIAL CLUES**—Observation of a glacier, such as the Alpine glacier illustrated here, can supply some useful information on current climatic tendencies and shed some light on the geological question of whether the present era is an interglacial period.

Simply measuring the extent of a glacier's terminal tongue to see whether it is growing or shrinking is unsatisfactory, because the fluctuations in the length of a glacier from year to year are little influenced by the way the tip of its tongue crumbles (Illustration 1).

Observation of the terminal moraines of Alpine glaciers shows that they are much larger than the tongues that now fill them; this indicates that the glaciers are retreating. However, such observations must be made on a worldwide scale to be completely meaningful. While indications are that glaciers are in retreat throughout the world, the question of post-Würmian climate has not yet been completely resolved, and will probably require much more extensive research.

It seems likely that the fickleness of the weather has always been a favorite subject of man, but today's climatic extremes would seem insignificant indeed to prehistoric residents of the earlier epochs of the Quaternary. The climate of that era was characterized by alternating cold (glacial) periods, during which the circumpolar regions and vast areas in North America and Europe were covered by enormous ice sheets, and hot (interglacial) periods, with temperatures higher than those of today, during which the ice sheets melted.

The history of glaciations is not yet fully known. Even the exact number of glaciations in some areas of the Earth—particularly Africa and other tropical regions where glaciers were not easily formed—is difficult to establish. Another obscure point is the origin of and the reason for the accumulation of glaciers in certain areas of the Earth. Hypotheses based on astronomical phenomena leave many questions unanswered. Other climatic elements that influenced snowfalls and thus caused the formation of glaciers are unknown.

While the causes and origins of the glaciations remain obscure, however, the history of their movements and the effects produced by their accumulations can be traced by careful geologic study.

2

RETREAT OF THE GLACIERS—The most important and most visual manifestations of glacial extensions occurred in the Northern Hemisphere where the ice sheet joined with the two enormous continental ice caps. These maps of the Finno-Scandinavian shield show the history of the retreat of the glacier at the end of a glacial phase.

Illustration 2a shows the maximum extension of the glacier; it covered the present locations of Jena, Warsaw, and Moscow and extended to the boundary of White Russia with the glacial Arctic Ocean. The existence of terminal moraines has established the point of maximum extension. In Illustration 2b, the Vistula glacial phase, the ice cap is smaller; this is the first stage of retreat, evidenced by the accumulation of morainal materials. The final retreat of the Cenozoic glaciers was not regular, but was characterized by halts and limited advances. Illustration 2c shows the boundary of the Scan-

a

dinavian and Finnish mo
glaciation. The lower par

of the Würmian
e Scandinavian

3

YOLDIA SEA, ANCYLUS LAKE, LITTORINA SEA—The enormous Scandinavian ice sheet, which joined with the Baltic Sea ice cap, attained enormous thickness almost comparable to those of the Greenland ice caps. This colossal accumulation of ice began pushing down on the continental mass of northwestern Europe. The continental blocks of sial are thinner toward the edges, and the pressure of the ice

caused the continental m
ably. When the ice cap
Finno-Scandinavian shiel
rise from the sea. This
the Earth's crust has n
Scandinavia is still slo
water.

Deposits of morainal an
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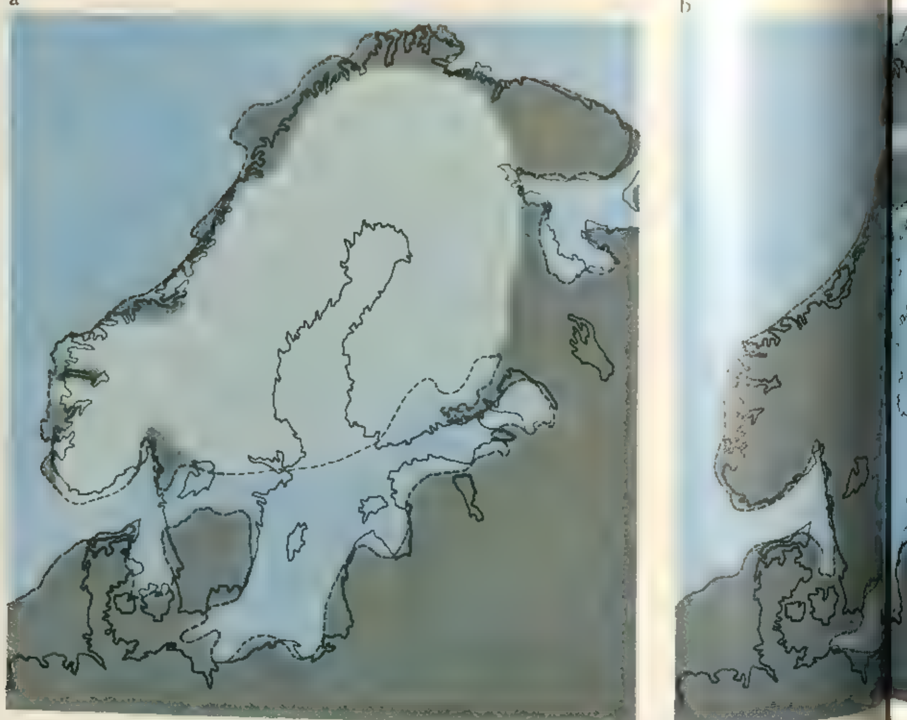


b

c

d

peninsula is al Stockholm and ree of the glaciers, while nki mark the fringes. The elevated areas in Norway, Sweden, and most of Finland are still covered by glaciers. Illustration 2d shows the situation at the beginning of the postglacial period.

era. Illustration part of the B tween Sweden covered by an given it the lusks (*Yoldia*) map, the ice extension, bu retreat. This hows the Yoldia Sea, that at today is wedged be- Finland, which was then eet. Paleontologists have Yoldia after certain mol- ved in its waters. In the at its period of maximum phase of considerable oughly 8,000 years ago, when the Baltic was connected with the North Sea, not as it is today, but by a passage immediately south of Stockholm and the southern boundary of the ice sheet.

Then, as now, this sea was not very deep, so that silt of glacial origin accumulated quite rapidly on its floor. These layers of silt have annual alternations of color and coarseness of particles; by measuring these layers, the exact age of the Yoldia Sea can be determined. *Yoldia* is a saltwater shellfish, confirming this sea's link with the North Sea.

Illustration 3b shows a somewhat more recent phase, during which the rising of Scandinavia after the retreat of the glaciers probably caused the separation of the Baltic Sea from the North Sea with the complete emergence of the land bridge between Scandinavia and Denmark. An internal sea was formed, or more properly, a lake, because it once contained fresh water and was inhabited by a typical freshwater snail. The fresh water probably came from the melting ice sheet; it accumulated in this huge lake that was connected with the North Sea by a stream of fresh water. Illustration 3c shows the last phase, dating back to about 6,000 years ago. This is the Littorina Sea, in which saltwater snails of the genus *Littorina* were abundant; they are still found in the varves of its sediments.

c

GEOGRAPHY OF THE PLEISTOCENE | of lands, seas, and ice sheets

The establishment of men as influential elements in terrestrial ecology occurred on a stage of Pleistocene geography, a stage that was itself undergoing enormous changes. Three main phenomena were involved in altering the geography of the Earth. The first phenomenon was the great regression of the sea at the height of the glacial ages; the second was the return of the sea to areas previously covered, as a result of the melting of the great ice sheets during the warm interglacial ages; and the third was the progressive filling of certain basins, such as that of the Po Valley in Italy. Enormous quantities of morainal detritus, eroded from the mountain chains by glaciers, were transported by streams and deposited in these basins.

Alternation of glacial and interglacial ages resulted in sea levels fluctuating by hundreds of feet. During glacial ages, the sea level probably stood as much as 122 m (400 ft) lower than at the present time; and during interglacial ages, it probably was several scores of feet higher than now. By studying the volume of glaciers and by measuring the height of interglacial marine deposits and the depth of shoreward sediments and submerged channels, such figures and information can be gleaned.

Within the framework of Pleistocene geography, consideration must be given to (1) the last orogenic phenomenon of the Tertiary, (2) the distribution of ice on flatlands and on high reliefs, and (3) the locations of regions that were transformed from seas into dry land.

THE EARTH DURING THE PLEISTOCENE— This map illustrates the major characteristics of Pleistocene geography during maximum glacial extension. During the Pleistocene, four stages of maximum glacial extension alternated with interglacial stages, during which the ice sheets and glaciers melted, except for those in the Antarctic and Greenland. During the interglacial stages of the Pleistocene epoch, the sea reinvaded all the known continental shelves, except those that had already been filled with great quantities of detrital materials.

In the Western Hemisphere, the great glaciations extended over the Rocky Mountains, the mountains of northern Alaska, and the Patagonian Andes. It is doubtful whether the equatorial Andes were ever covered with glacial masses comparable to those that covered the Alps and the Pyrenees in Europe. A colossal ice sheet covered nearly all of Greenland and northern Canada, pushing south of the Great Lakes region.

Ice also covered Iceland, Spitzbergen, Franz Josef Land, the New Siberian Islands, and the entire region extending from Ireland across England, Scandinavia, and northern Siberia. To the south, the ice sheet pushed about halfway down the continent of Asia, covered the upper basins of the Don and the Dnieper and finally crossed about half of Germany.

The Alps and the Pyrenees were completely covered by glaciation, as were the Caucasus the Himalayas, other mountain chains north of China, the Tien Shan, the Altai Mountains, the Yablonoi Mountains, and the area corresponding to Lake Baikal. Small ice caps existed in Tasmania and the southern part of Australia. In Africa, small glaciers almost certainly covered the Atlas Mountains, as well as Ruwen-

ITALY DURING THE QUATERNARY—Considerable volcanic activity occurred in Italy during the Quaternary; this activity actually was produced by phenomena of earlier epochs. During the Tertiary in Italy two successive orogenic phenomena had raised up the Alps and the Apennines. In both cases, fissures opened in the crust, and magma from the Earth's mantle came into contact with the surface of the Earth. The magma did not flow directly from the mantle to the surface, but formed into large plutons beneath the surface. Subsequent cooling of the plutons and the fissures joining them to the surface generated volcanic phenomena of fairly long duration (from 1 to 10 million years). Therefore, the origin of all Quaternary volcanic activity in Italy can be traced back to previous epochs.

The map shows how this activity spread throughout central and southern Italy, with volcanoes in Tuscany, Latium, and Campania, as well as in the Lipari Islands (Stromboli) and on the island of Sicily (Etna). The phenomena of volcanism and Apennine orogeny are interrelated.

zori and Kilimanjaro. The great amount of solar radiation, coupled with the relatively dry climate, kept the rest of Africa free of ice during the entire Quaternary.

Almost the entire continental shelves of North and South America were uncovered during the glacial extensions. Hence, the outlines of these continents differed little from what they are today, except that the Isthmus of Panama was much wider than it is at present. Madagascar was joined to the continent of Africa. In Asia, the Persian Gulf was almost completely closed, Ceylon and India were united, and the islands of Indonesia, Sumatra, Java, Borneo, and the Philippines constituted one vast landform, occasionally cut by geosynclinal seas. New Guinea was connected with Australia, which extended by means of a continental shelf all the way to the Great Barrier Reef. Japan was connected with the Asian mainland by a piece of land that was elevated slightly above sea level, but was completely free of water during the glacial ages. England was linked to the European continent, because the English Channel was completely dry. The Adriatic, too, was almost devoid of water; Sardinia and Corsica formed a single stretch of land.

During the interglacial ages, the ocean reinvaded the formerly occupied areas that were above sea level during the glacial Pleistocene, except for those regions that had been filled with silt deposits from glacial erosion. The outlines of the coasts then became very similar to what they are today.

The orange on the map identifies areas with small deposits of detritus, basically loess. The blue indicates areas with alluvium, often carried by glacial melt waters.

FAUNA OF THE QUATERNARY

Animals of th[illegible] [illegible]leistocene epoch differed very little f[illegible] those that may be seen in any zoo [illegible] The greatest changes that have [illegible] place in the Animal Kingdom ov[illegible] past two million years include the [illegible]ction of certain species —notably th[illegible] [illegible]antic ones—and the regression of s[illegible] forms that had evolved over a long [illegible]iod of time. The most important ch[illegible], however, was the appearance of [illegible]

The alter[illegible] of periods of glaciation with period[illegible] interglacial warmth was an influenti[illegible]tor in the acceleration of the evolu[illegible]ry process. This alternation in a te[illegible]rate region undoubtedly produced b[illegible]gical changes that profoundly alt[illegible] evolutionary cycles and greatly fav[illegible] the elimination of some species, the [illegible]ergence of others, and the mass migrat[illegible] of still others.

Scientists [illegible]e traced the lineage of mammalian [illegible]ms from the earliest part of the Ple[illegible]ne epoch down to the Holocene [illegible] Recent epoch (the last 11,000 yea[illegible] so), and they have detected onl[illegible]ght changes in specific characteris[illegible] in other words, they have found that [illegible] differences between mammals of the [illegible]cent epoch and their Pliocene ancestors are no greater than differences between related species.

← **SYMBOL C[illegible] PERIOD**—The cave bear, *Ursus spela[illegible]* was one of the most representative an[illegible]s of the Quaternary period; it was particularly representative of animals that were contemporaries of primitive men. The cave bear was widely distributed throughout Europe, where the history of primitive men and their associations with Quaternary animals is best known. Because this animal lived in caves, its remains have been well preserved. Conditions of the Quaternary—particularly the glaciations and subsequent massive flooding—in general did not favor the preservation of organic remains. Caves located in the mountains, however, were unaffected by glacial erosion, and over the years they became filled with sediments deposited by watercourses flowing through them. The remains of *Ursus spelaeus* and the remains of primitive men and their artifacts are found in these cave deposits.

The cave bear had adapted to life in a very cold climate, and it managed to survive both the glacial and interglacial periods before becoming extinct in fairly recent times.

The photograph shows an exceptionally fine specimen of a cave bear skull, which was discovered in Italy near Verona. The skull is a very recent fossil, consisting entirely of original organic material; even the teeth contain their original dentin.

The extent to which the plants and animals of the Earth have become adapted to the new environment since the end of the last glacial age is an indication of what can transpire over a span of about 11,000 years. The earlier glaciations must have had similar effects on life-forms. Inasmuch as the interglacial ages that followed the glacial ages (Nebraskan, Kansan, and Illinoian) lasted about 200,000, 300,000, and 100,000 years respectively, scientists infer that the regions from which the ice had retreated became completely re-covered with vegetation and repopulated with animals several times during the Pleistocene.

As previously indicated, mammalian life changed greatly both through the appearance of new forms and through the extinction of existing forms. Among the new mammals were zebralike horses, cattle, camels, certain kinds of elephants, rhinoceroses, and a woolly mammoth—a distinctly cold-climate form not known to have lived prior to the first glaciation. Horses and moose were important immigrants near or at the close of the Kansan glaciation (about 600,000 years ago).

The greatest number of extinctions occurred roughly from 5,000 to 10,000 years ago. North American animals that became extinct during this span of time included all the camels, horses, and ground sloths; two genera of musk oxen; peccaries; antelopelike ruminants; all but one species of bison; a giant, beaverlike animal (*Castoroides*); a stag moose; and several kinds of cats, some of which were as large as modern lions.

The huge mammoths, which had become common throughout the United States, also disappeared, as did the forest-dwelling mastodons, and the woolly mammoth of the tundra. Their extinction in North America, as well as in Europe, has generally been attributed to hunting by early men.

The appearance of men in North America was rather sudden, probably taking place when a land bridge connected North America with Asia. Today, of course, Alaska is separated from Siberia by the Bering Strait. However, the fossil record indicates that the Strait was a land connection one or more times during the Pleistocene epoch.

Not only may crustal warping have produced the bridge, but lowered sea level prevailed during the early and late parts of the different glacial ages when great quantities of seawater were still locked up in the ice sheets. The Japanese Current probably gave the Bering Strait area a mild climate and in all likelihood permitted the growth of long, thick grass, similar to that on the Alaskan peninsula. Both the immigrants and the emigrants traversing the Bering Strait appear to have been entirely cold-temperate or boreal forms.

Migration also took place between the American continents. Ground sloths emigrated from South America and traveled as far north as central Alaska. The North American horse and deer crossed the Isthmus of Panama to live in South America.

The Pleistocene mammals in Europe went through a striking series of changes, too. Fundamentally, the changes involved the steady evolution of certain species, as occurred among the elephants, rhinoceroses, and horses. At the same time, other forms became extinct in the face of competition from eastern immigrants.

Superimposed on this evolutionary progression, however, was an oscillation due to a north-south shift of animal population as the glaciers waxed and waned.

As a result of the alternation of cold and warm climates, the Quaternary actually was characterized by two different faunas, one typical of the glacial ages and the other typical of the interglacial ages. Each had well-defined features, which are discussed in another article. The fauna of the Pliocene epoch has already been described, and the primates have been distinguished from the other animals in order to give separate consideration to the classical fauna that preceded the appearance of men. Separating primitive men from other animals means, in a sense, identifying with them, and discovering how the Quaternary must have appeared to them. In studying Quaternary fauna, the interaction of men and animals must be kept in mind. Men had to compete with, and defend themselves against, many Quaternary animals. Other animals were indifferent to men and shared the forests and glaciers of the Pleistocene with them. However, men had amicable relationships with certain animals and soon succeeded in domesticating them.

FAUNA OF THE GLACIAL AND INTERGLACIAL AGES | some representative animals

In every glacial age, climatic changes exerted great influence on both subaerial and subaqueous habitats. The underwater forms of life were affected less than the terrestrial organisms, but underwent changes nevertheless. Certain species of algae became extinct, the aquatic flora made minor variations, and the lower fauna adapted for existence at different temperatures.

The period following a glaciation typically was marked by the migrations of higher animals. In the sea, these migrations usually were not accompanied by natural-selection processes; progressive variations in temperatures in the sea induced migrations, but did not bring about the extinction or appearance of species.

In contrast with the relatively minor changes in marine life, a true revolution occurred among terrestrial animals following each period of glaciation. Some animals adapted readily to the climatic variations of glacial and interglacial ages, despite the fact that the former were exceedingly cold and the latter were often very warm. Other animals, especially those from the Alpine regions of Europe, took refuge in the mountains when the temperature rose during an interglacial age. Still others, which were unable to adapt satisfactorily to the climatic change, became extinct.

Naturally, herbivorous animals could not live where ice covered the ground, but they could survive on the edges of the glaciers. Carnivores, however, which could live on or off glaciers, often preyed on herbivores.

Intercontinental migrations took place during interglacial ages, particularly when the temperature rose, but before the melting of the ice resulted in the submergence of the land bridges connecting the continents. For example, at the beginning of the Quaternary, some types of elephants, rhinoceroses, hippopotamuses, lions, and other animals typical of warm climates appeared in Europe.

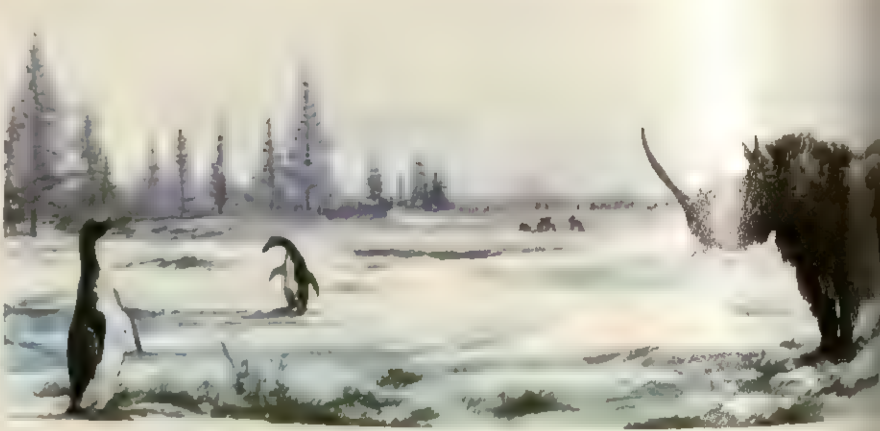
The cold conditions of the glacial ages also encouraged animal migrations, bringing typically polar animals into regions that are now subtropical. For ex-

1

FAUNA OF THE INTERGLACIAL AGES—In contrast with the bitter cold of the glacial ages, the interglacial ages were characterized by a warm, even subtropical, climate. *Corbicula fluminalis* (a mussel) and *Zonites acieformis* (a snail) exemplified the organisms that populated the Earth's waters during the interglacial ages.

Many animals of the interglacial ages were virtually the same in size a[illegible] shape as other animals characteristic of [illegible] glacial ages, but they adapted differen[illegible] to temperature. The proboscideans (eleph[illegible]) constitute a good example: *Elephas* [illegible]*uus* (shown in this illustration) lived in [illegible]pe during the interglacial ages; it was [illegible] similar to the mammoths of the glaci[illegible]es (shown in illustration 2), but its sk[illegible]nd tusks had

2



FAUNA OF THE GLACIAL AGES—This landscape is a condensed portrayal of the appearance of the Earth during the glacial ages and the most characteristic animals of those times. As a composite, it is not wholly accurate.

Scientists have been able to reconstruct the ice-age fauna rather easily, because fossilization processes have been incomplete; remains of animals living during the glacial ages have been either totally destroyed or preserved almost intact, with little or no replacement of original materials.

Some glacial-age animals were drawn by primitive men, and the drawings have been of immense help to paleontologists. Attempts to reconstruct the outward appearances of these animals on the bases of skeletal remains and comparisons with animals living today indicate that primitive artists portrayed the ice-age animals with great accuracy.

Among the characteristic animals of the glacial ages was a kind of penguin whose

different shap… ıd its body had a different
kind of cove…
Cave-dwell… ımals, such as *Ursus spe-*
laeus (the ca… ear in the left foreground),
Hyaena croc… *pelaea* (the cave hyena),
and *Felis leo*… a (the cave lion), still lived
during interg… ımes. Animals very similar
to modern h… and donkeys were charac-
teristic of th… t plains. The descendants

of these equids have survived unchanged into modern times, particularly in eastern Asia. Many species of cervids (deer, elk, and moose) also existed during the interglacial ages, and some of them continue to live today. Other cervids, such as the enormous *Megaceros hibernicus* (the Irish elk), have become extinct. The reindeer was practically the same in interglacial times as it is today.

Alongside these animals were others that disappeared during the Pleistocene. Among them were *Megatherium*, a gigantic, toothless ground sloth of the Pleistocene (shown at the extreme right of the illustration) and *Macrauchenia patachonica*, a rhinoceroslike protoungulate that first appeared during the Early Pliocene. Both these animals lived chiefly in the South American pampas.

remains have been found in caves overlooking the sea in southern Italy. The chamois, ibex, and marmot were typical of animals living in the Alps during those times; they are still found in cold, high-altitude regions, where the climate is typical of the glacial ages. These animals and others with similar habits are also found today in Canada, where the climate is not unlike that of the glacial ages.

The glacial ages were also characterized by some animals that adapted to the cold to a greater or lesser extent. The ancient elephant was replaced first by *Elephas trogontheri* and then by *Mammuthus primigenius* (the woolly mammoth), which had a very long, woolly coat. This long coat was very utilitarian from a biophysical point of view. The mammoth had a very large but stocky body with a very low surface-to-volume ratio, which served as a natural defense against the cold and against fluctuations in temperature. The surface, which permitted thermal exchange with the interior, was very small per unit of volume. Nevertheless, if the animal lay on the ground to rest, it could still suffer from the cold as a result of its contact with the ice. Hence, the long hair on the neck, chest, and belly helped to insulate the mammoth from the cold when it reclined. The same sort of adaptation occurred in other animals, such as *Tichorhinus antiquitatis* (the woolly rhinoceros, shown in the center of this illustration) and *Rangifer tarandus* (a kind of reindeer).

3

REPRESENTATIVE OF A MODERN FAUNA— This is the skeleton of a perfectly preserved *Equus hemionus*, a member of the family Equidae. This species of donkey lived in Asia during Pleistocene times and still exists today. Some members of the species have been domesticated, while others live in the wild state in Mongolia.

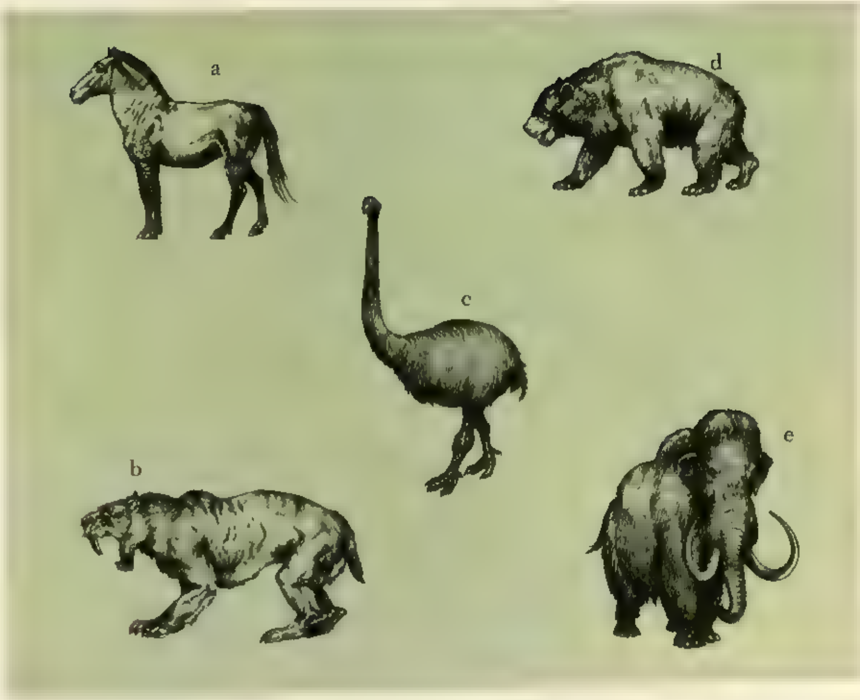
ample, cav[illegible] a peninsula in southern Italy have [illegible]d the fossil remains of a species of [illegible]uin. Discoveries of this nature sup[illegible]e hypothesis that Quaternary gla[illegible]vasions were caused by overall de[illegible] in temperature rather than by s[illegible]cal precipitation phenomena. Al[illegible]h summers are generally warm toda[illegible]ncrease in precipitation during the [illegible]nd winter would suffice to extend g[illegible]rs beyond their present boundaries. [illegible]sequently, glaciations in the past co[illegible] have been produced by precipitatio[illegible]henomena; however, the presence in [illegible] of animals typical of the ice ages—a[illegible] that require a low year-round tem[illegible]re—suggests that the glaciations w[illegible]ught about by an overall temper[illegible]decline accompanied by an increas[illegible]ecipitation.

In Nort[illegible]rica, forms that lived on the tundra [illegible] to the ice front included the wooll[illegible]moth and the caribou. In the su[illegible]tic forest dwelled mastodons, moo[illegible]giant beavers, deer, and bears. Far[illegible]removed were other elephants o[illegible]ammoth line as well as tapirs, p[illegible] and carnivores. Elephants li[illegible] the central Great Plains and wer[illegible] of the late glacial forms in Florid[illegible]ng with camels, wolves, and bears. [illegible]nel fossils found in central Alaska m[illegible] have been interglacial.

Limitations of space preclude a detailed list of the animals that lived during each of the four glacial ages and each of the three interglacial ages. Generally speaking, however, two types of fauna, glacial and interglacial, existed during the Pleistocene. Many species failed to survive from one glacial age to the next or from one interglacial age to the next; others survived throughout the entire Pleistocene epoch, but vanished during the Recent or Holocene epoch; still others survived both the vicissitudes of the Pleistocene and the encroachments made by men, and still exist today.

Certain representatives of the Quaternary fauna were holdovers from preceding periods, particularly the Tertiary. Some animals that were widely distributed during the Pliocene survived into the Quaternary, but vanished during the Pleistocene. Finally, some of the Quaternary fauna were continuations of forms that had lived during the Mesozoic era or earlier.

4



THE ROAD TO EXTINCTION—The animals shown in these drawings are representative of Quaternary animals that have recently become extinct or exist today in limited numbers. Those that do survive may be considered living fossils, for they presently reside in habitats that are either little known or severely limited.

Two animals that have survived in very limited numbers are *Equus przewalskii* or Przhevalski's horse **a**, of which only a few specimens exist in the wild state in eastern Europe, and *Ursus gygas* **d** an enormous Alaskan bear.

The European bison is another vanishing animal. The few remaining specimens on the European continent were captured and placed in the Munich zoo to prevent their complete extinction. They continue to reproduce in captivity in an environment that has been made as similar as possible to their natural habitat. The American bison has fared better, but it came dangerously close to eradication. No less than 60 million bison lived in North America when the first settlers arrived, but indiscriminate hunting almost eliminated these animals from the face of the Earth. Only very strict and timely conservation has saved the species. All told, only a few thousand of these animals live today.

The moa, *Dinornis maximus* **c**, was a gigantic Australian bird that stood over 3 m (about 9.5 ft) high; the fact that its remains have been discovered neither fossilized nor covered with sediments indicates that this enormous, flightless bird became extinct in quite recent times.

Some present-day tigers are descended from a Pleistocene machairodont or saber-tooth cat **b**; they live in a restricted habitat in southern Siberia, where they constitute a limiting factor to any increase in the boar population. They are the largest tigers living today.

The woolly mammoth **e**, whose remains have been discovered in Siberia and Alaska, was another animal that lived not long ago—geologically speaking. Bodies of mammoths buried for thousands or perhaps tens of thousands of years have been so well preserved by the cold that, in cases, the flesh was still edible when the specimens were discovered.

1

INTERGLACIAL FOSSIL—This beautiful, but imperfectly preserved, fossil is an elm leaf, from a species (*Ulmus campestris*) that still exists today. The fossil, which dates back to an interglacial age of the Middle Quaternary, was preserved in a clayey sediment. Climatic changes during the Quaternary caused the flora native to more northerly latitudes to shift southward to Mediterranean latitudes during the glacial ages; during interglacial ages, tropical flora such as *Rhododendron ponticum* shifted northward to the boundaries of Arctic regions.

The Quaternary glaciations had profound effects on the flora as well as on the fauna, but the types of plants existing today are virtually the same as those that lived during the earlier parts of this period. The principal differences are variations in distribution, which have resulted from climatic changes. A particular area was characterized by one type of flora during the cold glacial ages and by another type of flora during the warm interglacial ages. With the growth of the ice sheets, the forest belts moved southward, and tundra and cold steppe covered much of the periglacial zone. Each time that the ice retreated, the vegetation belts moved northward again, producing a succession of plant associations. When scientists discover evidence of the botanical groups populating a region, they can reconstruct with great precision the climate of that region.

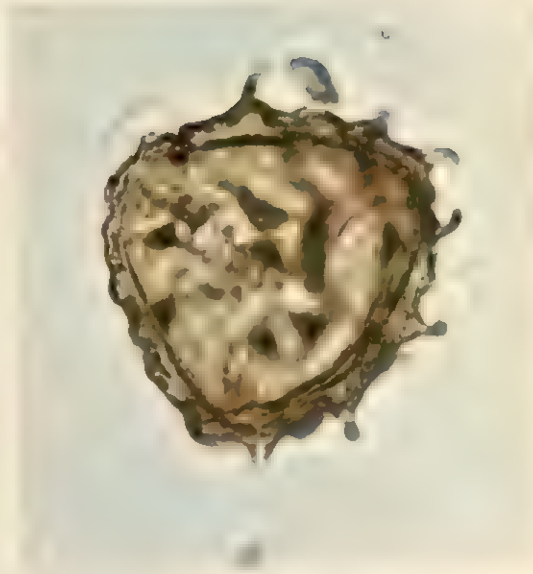
One way of establishing the climatic pattern of a region depends on the discovery of numerous, well-preserved plant macrofossils. These specimens must be in good enough condition to permit identification, and they must be sufficiently plentiful to permit a statistical compilation of species.

Another method is based on the determination of the frequency with which the pollen of these plants is found in sedimentary deposits. Because plant pollen is highly resistant, it endures for a long time. Pollen is abundant in deposits of the Quaternary period. Inasmuch as each plant has a typical pollen, scientists can easily reconstruct the type of flora of a given area.

The pollen method enables scientists to determine the climate of a particular region during the past, because it permits them to establish the botanical makeup of that region. However, this method has not enabled scientists to determine the climatic trend of the present day. They want to know whether the Earth is becoming colder or warmer. If it is becoming colder, the last interglacial age is over, and another glacial age is beginning. If it is becoming warmer, the interglacial conditions are continuing and even becoming accentuated.

The question concerning present-day climatic trends cannot be answered for the moment, because pollen data are often contradictory. This does not mean that the pollen method is faulty. The discrepancy may be due to local micrometeorological phenomena. Measurements of glacier movements also yield contradictory evidence; in some regions glaciers are retreating, but in other areas they are advancing. Studies conducted during the International Geophysical Year did not produce conclusive results. Therefore, although the evidence seems to indicate generally that the climatic trend is in the direction of accentuated interglacial (warmer) conditions, the question is still open. Nevertheless, the fossil pollen method provides a useful basis for checking other climatic considerations and for furnishing information about the climatic conditions during more remote epochs.

3



A GRAIN OF POLLEN—This is a pollen grain from *Selaginella selaginoides*. According to the plant species, pollen grains differ greatly in size, shape, color, and principally surface appearance.

Usually, plant pollen is quite resistant, lasting for thousands of years. Therefore, paleobotanists find it relatively easy to reconstruct the plant composition of a given area, because all they need to do is to distinguish among the pollen grains produced by the principal plant species. These grains ordinarily differ greatly from one another and are, therefore, readily recognizable, even though they are not perfectly preserved.

THE PRESERVATION OF PLANT FOSSILS—Plant fossils of the Quaternary period are well preserved only when they have been fossilized in fine-grained sediments. Such fossils, which still possess all their internal structures, cannot be distinguished from similar fossils of the preceding period, because once they have been preserved in this manner their appearance does not change in less than 20 to 40 million years. Fossils of this kind are relatively rare, because the preservation of delicate leaves—the only parts that provide positive plant identification—is very difficult.

The leaf shown in this photograph belongs to a species in the family Aceraceae. The specimen was fossilized in sediments transformed into calcareous rock. The fossil was discovered near Cavriglia, in the province of Arezzo, Italy.

2

POLLEN SPECTRUM—An important characteristic of pollen grains is their great resistance. These tiny particles must often travel a great distance from the plant that produced them to the plants that will receive them. Moreover, the pollen must be able to endure on the ground for a long time. Because of these exceptional characteristics, pollen that was produced thousands and even tens of thousands of years ago has survived to the present day, buried in the ground. Each plant produces its own kind of pollen; therefore, scientists are able to reconstruct the flora of a particular area at a given time by determining which types of pollen are contained in a given deposit. Scientists know, of course, that pollen may be carried long distances by the wind. Nevertheless, when they find that a particular kind of pollen consti··tes a large percentage of the organic ma··rial in a rock stratum, they can assume ·at the pollen originated fairly nearby.

How can paleobotanists ·construct the events that led to a particula· ·ttern of pollen distribution? Consider, for · mple, an area where a forest of firs and pi· exists in close proximity to a lake. The c· osition of this forest changes—and has ch· ·d—in accordance with changes in clim· conditions. In fact, many plants are so se· ·ve to climatic changes that they cannot · ·ve when conditions vary rapidly or e· ·ively. In this example, the forests during ·acial age consisted chiefly of firs (Illus ·n 4a), which spread pollen during the · ·g. The pollen was carried by the wind a· ·stributed over a vast area, not only in the ·st, but also in the lake, where it was subs· ·ntly deposited together with mud near th· ·ores. In other words, an inorganic sedime· ·ntaining some fir pollen was formed durin· ·is first phase.

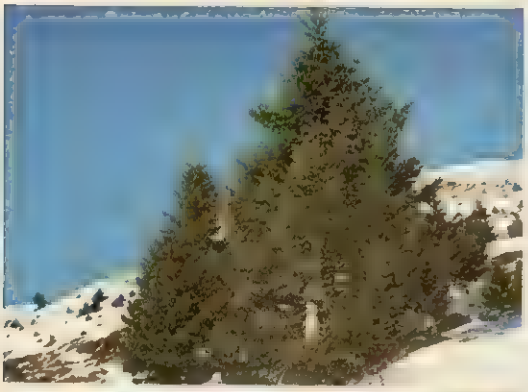
Time passed, and the c· · conditions of the glacial age were replac· ·y the warmer conditions of an interglacial · Pines superseded firs as the dominant · s in the forest (Illustration 4b). As a consec· ·ce, the pollen composition of the sed· ·ary deposits changed; the layer contain· · fir pollen was covered with a layer contai· predominantly pine pollen.

In time, glacial conditi· returned, and consequent changes took p· in the composition of the forest (Illust· · 4c). The fir pollen was again deposite· ·his time in a layer of sediments overlyi· ·e layer containing pine pollen.

Another interglacial age ·wed this third phase. Once again the pi· ·became more numerous at the expense · · firs (Illustration 4d), and once again, th· ·e pollen was deposited in a layer of s· ·nts over the fir-pollen layer.

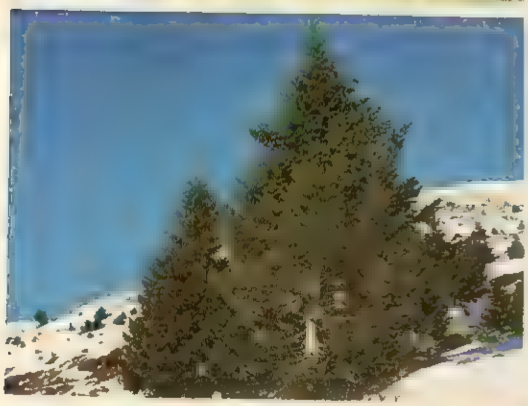
To study pollen, a paleo· · ·nist must find a place with relatively rece· ·ddy deposits, which demonstrate (from th· ·ological structure of the surrounding ter· · that they are the direct continuations of ·dimentary deposits formed during precedi· ·millennia. Having discovered a spot whe·· the sediments are soft for several meters do··, the scientist drives a thin steel tube into the ground thereby causing it to fill with mud from the superficial layers. Once he has extracted the tube from the ground, he removes the mud core, cuts it into slices, and labels each slice as to the depth from which it was extracted.

In the laboratory, the scientist dissolves the fragments in water and separates the pollen from the inorganic residue. He then makes a microscopic examination of the organic material to determine the percentages of pollen from different species of trees. Following this step, he may construct what is known as a pollen spectrum of the area under study; such a spectrum is shown as a graph at the right of the photographs. The broken line indicates pollen from fir trees (cold-climate plants), and the solid line represents pollen from pine trees (warmer-climate plants). The spectrum shows that from one age to the next, the pollen varied between 10 percent and 90 percent, indicating that the plant composition of the forest was greatly shifted toward one or the other of the plant species.



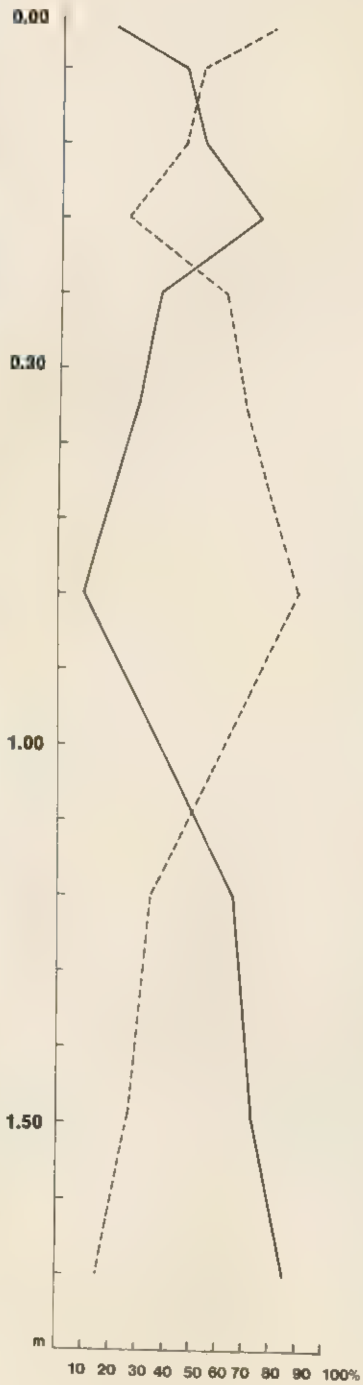
4a

4b



4c

4d



THE APPEARANCE OF MEN | origin of the hominids

The Quatern[illegible] unquestionably, is the period of m[illegible] their total history—recorded and [illegible] recorded—has transpired during this [illegible] of geologic time. The remains of [illegible] constitute the most important inde[illegible] ls of this period. Moreover, the a[illegible] ts and other signs of human acti[illegible] ovide interesting information conc[illegible] the evolutionary and cultural hist[illegible] men.

When an[illegible] what manner did men appear on [illegible] Earth? This question, which is of [illegible] than biological or paleontological [illegible] st, has not yet been answered. [illegible] ugh the origin of men was relative[illegible] ent, it occurred in various stages, [illegible] no clear-cut beginning can be estal[illegible] d. Certainly, men were not present [illegible] g the Tertiary; therefore, their [illegible] must be attributed to the Quatern[illegible]

MEN

Present-da[illegible] are clearly distinguishable from [illegible] er living animals. Even the less h[illegible] evolved primitive men were distin[illegible] different from the most highly evo[illegible] anthropoid (manlike) apes. Ho[illegible] t the beginning of the Quaternar[illegible] body structure, skull shape, and [illegible] al capacity of men probably were [illegible] remarkably distinct from those of th[illegible] ighly evolved anthropoid apes, which [illegible] re already quite advanced by that tin[illegible]

In human paleontology—or more precisely, paleoanthropology—men are described as beings whose activities are not limited by their sensory organs and limbs; rather, they are beings whose capacities for reflection and abstraction enable them to create tools for their own use. In other words, toolmaking is considered a definite human activity, which serves to distinguish true men from highly evolved anthropoid animals.

Obviously, this definition does not satisfy all people, for it takes no cognizance of the moral significance of human thought. Nevertheless, from a strictly paleoanthropological point of view, the definition is quite useful. In many instances, scientists have acquired precise information concerning the types of industrial activity carried on by prehistoric men; on the other hand, no satisfactory means exist for recognizing or identifying the intellectual and moral activities of these primitive people. Human fossils dating back to about 15,000 years ago have often been found in association with signs of artistic activity, which testify to the intellectual level attained by human beings at that time.

The appearance of men may be equated with the appearance of humanoid forms associated with activities of a superior nature. Even though the appearance of men can be attributed to the beginning of the Quaternary, that appearance was slow and gradual. Men appeared along with other forms that were very similar to the higher anthropoid apes, but that were definitely not human.

A NEW EVOLUTIONARY FORM

Paleoanthropology is concerned not only with anatomical characteristics, but also with the evolution of higher activities. In deposits from the first half of the Quaternary, traces have been found of just one particular type of primitive man, *Australopithecus*, who had a very limited intellect. Some evidence indicates that *Australopithecus* made very crude stone tools; therefore, according to the definition of man in paleoanthropology, *Australopithecus* was a human being. Later on, human beings came to make much more refined tools, not only of stone, but also of various metals.

The extremely primitive men who lived during the first half of the Quaternary had cranial capacities of about 600 cm^3 (about 36.5 $in.^3$)—less than half the capacity of modern men. Therefore, these early men were endowed with a low intellectual capacity; they did not speak an articulate language, and for a long time they were incapable of kindling fire and cooking food.

Evidence furnished by these primitive men establishes a fact of major importance for the history of evolution: men apparently evolved on their own. The hominids (men) and the pongids (anthropoid apes) probably sprang from a common ancestor, but the two lines evolved separately. The pongids followed an evolutionary course by which they became adapted for an arboreal existence, and their skeletal structures, their limbs, and their teeth became specialized for this kind of life. The hominids, on the other hand, followed a course by which they became adapted for life on the ground; the structural modifications in the pelvis, skull, and limbs enabled them to assume an erect posture and a bipedal means of locomotion, while changes in dentition also equipped them for their terrestrial existence.

A MILLION-YEAR VOYAGE

The hominids who succeeded one another during the Quaternary must be considered as representatives of races that arose, evolved, and then vanished as entirely independent but collateral phenomena. In some cases, one race or form appeared rather suddenly and supplanted a preceding form, as when the race known as Neanderthal man disappeared and was replaced by the race of more modern men, known as Cro-Magnon men. This replacement occurred near the end of the last glaciation.

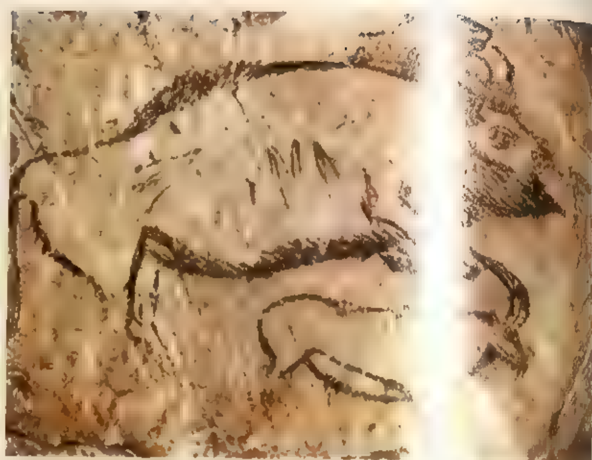
The appearance of these newer human forms was accompanied by the appearance of new types of intellectual and industrial activity. For example, one race of men may have lasted for 200,000 years, making relatively little progress. Then, rather suddenly, great strides were made, marked by the appearance of activities that evolved in a way substantially different from those previously known.

Living at the same time as primitive men would have been a fascinating adventure; certainly it would have been dangerous, because the primitive men would have viewed other hominids, not as brothers, but as competitors, enemies, or interlopers, who had to be eliminated. Communicating with them by means of language would have been very difficult if not impossible, at least during the first half of the Quaternary, for they did not know how to speak. Nevertheless, these primitive men were much more similar to modern men than to the anthropoid apes (gorillas, orangutans, and chimpanzees) of today; moreover, they possessed the amazing ability—far superior to that of any animal—to produce objects and to repeat operations typical of modern human beings.

The behavior of the hominids who appeared during the last glaciation was completely different from that of the men they replaced. Cro-Magnon men

1a

1b



1c

THE ARTISTIC ACTIVITIES OF PRIMITIVE MEN — For primitive men, art had an essentially mystical character—just as it has for many people living today. These photographs show some beautiful examples of well-preserved rock paintings. Two of them (Illustrations 1a and 1b) were discovered in the caves of Niaux in the Pyrenees, while the third (Illustration 1c) was discovered at Levanzo in the Egadi Islands off Sicily. Both the paintings and the graffiti testify to the sure hands of primitive artists.

Other outstanding murals have been found in caves in southern France and northern Spain. The cave paintings found near Lascaux, France, are perhaps the most famous of all the artistic works of prehistoric man. Undoubtedly, paintings were also made in the open air, but they have not survived to the present day.

were capable of almost all the activities of modern men, with a few exceptions, such as writing. The cult of the dead, art in almost all its manifestations, clothing, agriculture—all were represented in the culture of men who lived about 15,000 years ago, at the end of the Pleistocene. Then, some 5,000 years ago, men began to work with metals, fashioning weapons and implements from bronze. Many civilizations that have vanished and that are described in history books were cultures of this kind. For example, the ancient Egyptian civilization of the so-called Bronze Age was characterized by its picture writing, called hieroglyphics, which probably was a derivation of primitive art.

THE SEARCH FOR MAN'S BIRTHPLACE

The first discovery of fossils that provided important clues to man's past took place in Europe, in the Neanderthal Valley of Germany, in 1856. The next notable finds were in Asia—in Java in the 1890s and in China, near Peking, in the 1920s.

Even a casual examination showed that the Asiatic fossils were far older than the European ones. The skulls were ape-like, though the shape of the leg bones made it clear that the creature stood erect on two feet. The Peking fossils were found along with charred bones and chipped-quartz knives—evidence that this hominid, now generally called *Homo erectus*, used fire and made tools. Obviously, Peking man had progressed a long way from the tree-dwelling, plant-eating primates that were his ancestors.

The Java and Peking finds were widely publicized, and for a while Asia was thought of as the place where man first lived.

In 1924 Dr. Raymond A. Dart identified fossils found in South Africa as belonging to a group of previously unknown hominids that he named *Australopithecus*. Dart called this group "an extinct race of apes intermediate between living anthropoids and man." Whether classified as man or as ape, *Australopithecus* represented a stage of development much earlier than *Homo erectus*, and pointed

to Africa, ra[illegible]r than Asia, as man's place of origin.

The mos[illegible]iting chapter in the long story of ma[illegible]arch for his ancestors began in 193[illegible]n Dr. Louis S. B. Leakey and his wi[illegible]Mary, began a systematic exploration [illegible] the Olduvai Gorge in Tanganyika [illegible]ow Tanzania) in Africa. This 25-m[illegible]ng segment of Africa's great Rift [illegible] proved to be an incredibly rich s[illegible]ouse of both fossils and stone tools[illegible] very primitive implements call[illegible] pebble tools" (hand-sized rocks brok[illegible] just one end so as to produce a cu[illegible] edge) were found in abundance [illegible]ong with stone axes and knives of la[illegible] periods. In just one part of the vall[illegible] Leakey identified fossils from 100 d[illegible]ent extinct animals.

The Leak[illegible] worked at Olduvai Gorge for 28 year[illegible]fore finding the fossil evidence of e[illegible]man they sought. On July 17, 1959, [illegible] Leakey, working alone because h[illegible]sband was ill, found human teeth [illegible] the rubble of an eroded hillside. A[illegible]ful search revealed parts of a jaw, [illegible] and skull of what may be the w[illegible] earliest known human. The Leak[illegible]med their find *Zinjanthropus boise*[illegible]

The sit[illegible]he discovery turned out to be a c[illegible]ite on the bank of an ancient lake[illegible]merous pebble tools were found, al[illegible] with the bones of small animals, i[illegible]luding frogs, birds, rats, young pig[illegible] and a snake. Most of the bones we[illegible] broken but none were charred, indicating that the animals had been killed by man and the meat eaten raw. There was nothing to indicate that *Zinjanthropus* was capable of hunting and killing large animals.

The first tests of the radioactive decay of elements in lava flows covering the site indicated that *Zinjanthropus* lived 1,750,000 years ago. A later test indicated that 500,000 years ago was a more likely estimate. The absolute age of a fossil in years can be determined only rarely with present methods, and the results of two different tests on the same fossil may produce widely differing results.

Some authorities maintain that *Zinjanthropus* is not generically distinct from the fossils found earlier in the Transvaal region of Africa, and group them together in the genus *Australopithecus*. Other authorities accept *Zinjanthropus* as a separate genus and divide the other fossils into as many as four different genera. Slight differences do exist, but they very likely may be no more than a geographical variety.

At a slightly lower level in the Olduvai deposits but near *Zinjanthropus* was found a jaw that shows dentition characteristic of *Australopithecus*. Leg and foot bones and a partial skull were found later. The name *Homo habilis* was given to this individual, but it seems almost certain that it is only a geographic variant of *Australopithecus*.

The question arises whether *Australopithecus* could have been the ancestor of later hominids, including *Homo sapiens*. There appear to be no sound morphological arguments against such an inference; indeed, the *Australopithecus* conforms very closely to theoretical postulates for one phase of hominid evolution. Careful appraisal of the anatomical structure makes it clear that, in spite of the primitive characters retained in the size of brain and jaw, *Australopithecus* had already advanced a considerable way in the direction of human development and quite opposite to the direction followed by the anthropoid apes.

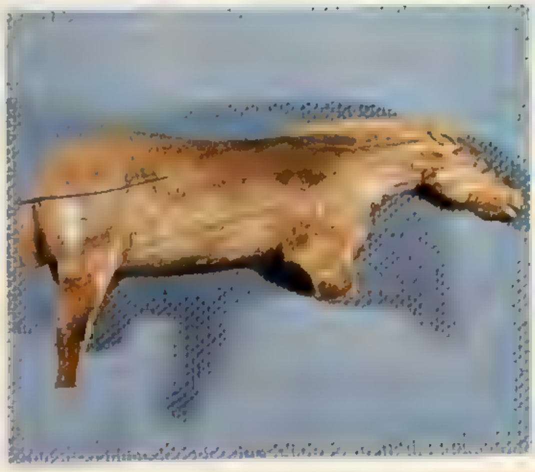
Since the discovery of *Australopithecus* it has generally been accepted that man's first home was Africa. Continuing anthropological and archeological research on that continent will probably, in the years to come, provide more information about man's distant past.

It is safe to assume that ancient man left Africa and migrated to the other continents during a period of glaciation, when much of the Earth's water was piled up in the form of great ice sheets that spread out in all directions from the poles. This was a good time for traveling —the level of water in the oceans was lower than it has ever been, before or since, and vast areas of ocean bottom were exposed and dry. These conditions created land bridges that connected the continent of Africa with the landmasses of southern Europe, northern India, southeastern Asia, and Australia.

By the time the continental glaciers melted and the level of the seas rose, man had established a foothold on all these landmasses.

2a

2b



ARTIFACTS—Artifacts such as these chipped stones (Illustration 2a) and worked bones (Illustration 2b) are indicative of industry requiring a considerable amount of intelligence and skill. Hominids capable of producing them had already reached the upper stages of intellectual evolution. Actually the men who produced these artifacts were relatively far advanced; they practiced the cult of the dead, communicated with one another in verbal language, possessed considerable artistic talents, and were on the verge of practicing agriculture.

←**SYMBOL OF** GE — The first skull of a primitive man n became the symbol of the last glaci mian) age in Europe, was discovered in eanderthal Valley in western Germany nged to a man who was named *Hom derthalensis* (Neanderthal man). He had arge cranial cavity, about 1,450 cm^3 (a 4 $in.^3$), and he spoke an articulate lar He was a primitive man, but also a rel modern one; he was adept at chipping 1 he practiced the cult of the dead.

The evolut the human species has taken plac relatively brief span of time, comp vith the duration that life has be Earth. The first men to appear—pro about a million years ago, but p even two million years ago—were similar to anthropoid apes, but rger brains. They did not possess of the superior functions that llv characterize human beings, pa lv the functions of language. No ss, they could be considered m only because they had greater c pacity than other animals, but also because they were capable of fabricating crude stone implements—a feat that seems to be beyond the capability of even the most highly evolved anthropoid apes, such as gorillas and chimpanzees.

ANATOMICAL CHARACTERISTICS OF PRIMITIVE MEN

During the past 200,000 to 300,000 years, the evolution of men has taken place with lightning speed. This span of time was marked by the appearance of species endowed with the cranial capacities and anatomical characteristics very similar to those of modern men.

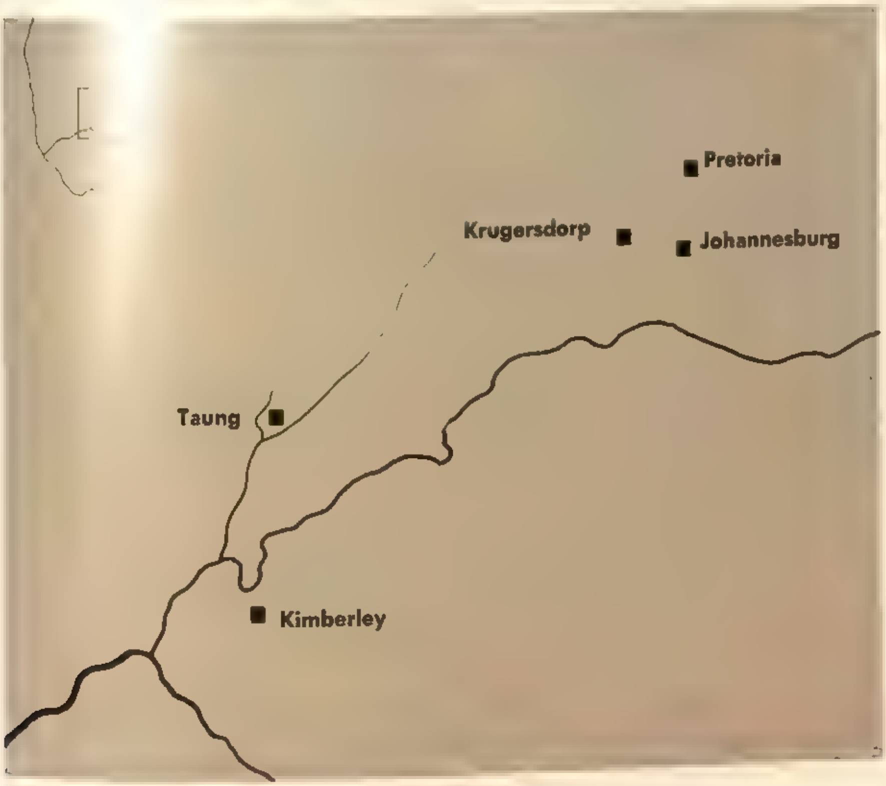
Anatomically, the earliest men were characterized by a small cranial capacity, in comparison with that of modern men. The crown of the head was set far back with respect to a very prognathous dentition; that is, the jaw projected beyond the upper part of the face. This latter characteristic derives from the resemblance of the primitive men to primate forms, which in turn resembled carnivores and herbivores. Particularly in the earliest species, the crown had an almost spherical shape, and it was very heavy, in some species attaining a thickness of as much as 10 to 20 mm (about 0.4 to 0.8 in.). Some primitive species had a sagittal crest on the top of the skull, similar to the crest found in modern gorillas.

Another characteristic of primitive men was the presence of very heavy brow ridges, which were in keeping with the powerful skull vault. The brains of most primitive animals with large skulls were hidden in a recess, well protected from blows. In primitive men, the brow ridges served to protect the encephalic mass, which could not be recessed because of its expanded size. The eye sockets were weak points in the skull structure, and the brow ridges helped to protect them. Therefore, the mechanical design of primitive man's skull was rather simple.

Primitive men were also characterized by robust dentition. Often the canines protruded considerably, in comparison

2

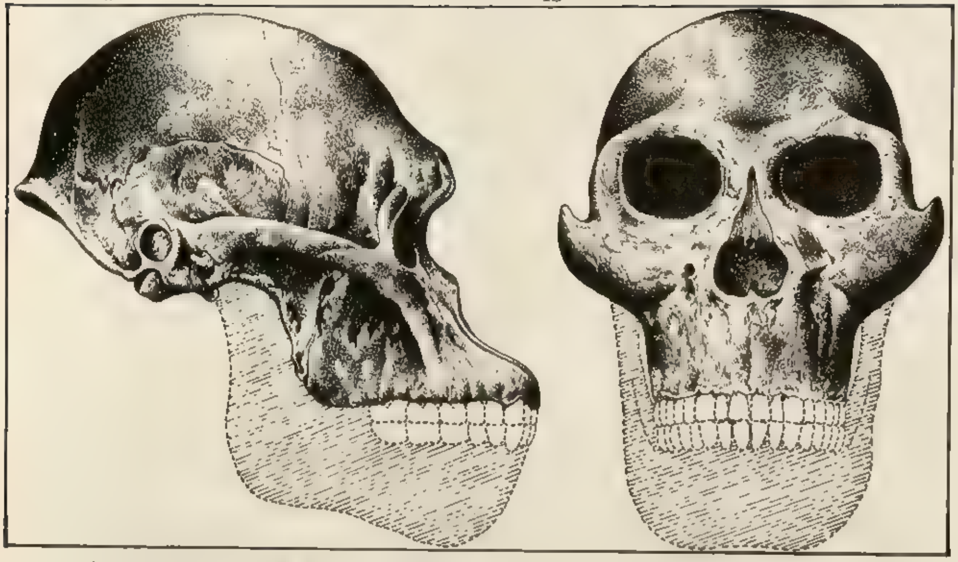
AUSTRALO NE ZONE — *Australopithecus* is the n ame of a group of hominids whose ske ve been discovered in Africa. This m vs the sites of some of the most impo in South Africa; more recent disco ve been made in the Olduvai Gorge in Tanzania. The australopithecines constituted the oldest human species of the Quaternary period; these primitive men were characterized by a modest cranial capacity of about 600 to 700 cm^3 (about 36.6 to 42.7 $in.^3$).



3

FIRST FIND—This is a photograph of the first skull discovered in the Neanderthal Valley, near Düsseldorf, in 1856. The skull is incomplete (the jaw is missing), but its characteristics suffice to establish it as the skull of a human being.

4a 4b



AUSTRALOPITHECINE SKULL—These two drawings illustrate the extremely primitive shape of the skull of *Australopithecus*. In some ways it resembled the skull of some present-day anthropoid apes, even though some undoubtedly hominid characteristics are recognizable. Among the primitive characteristics of this skull are the great thickness of the bones and the pronounced prognathism or protrusion of the jaw beyond the upper part of the face. The teeth, of course, are much smaller than the teeth of anthropoid apes, and, indeed, are completely consistent with the teeth of men.

with the other teeth. However, in no case did the canines reach the exceptionally large proportions of those of the anthropoid apes; in certain species of anthropoids, the canines were twice as long as the other teeth. The fact that the canines of primitive men were substantially shorter than the canines typical of the more primitive apes serves as evidence of the distinct separation between primitive men and other primates.

The jaw of primitive men was prominent and robust, with conforming dentition; the bones of the skull vault were joined with sutures, which became more and more complex as evolution toward modern man progressed. Therefore, the characteristics of the most highly evolved species were reduced prognathism, a smaller jaw and smaller teeth, less spherical skull shape, and a thinner skull vault. The most important characteristic, of course, was the expanded cranial cavity, which increased over a span of a million years or so from about 600 cm^3 (about 36.5 $in.^3$) to approximately 1,350 cm^3 (about 82.3 $in.^3$).

Parallel to the development of the anatomical structure of the skull was extensive development of the pelvis and limbs. Primitive men had an erect posture, even though some of the earlier species were somewhat stooped. In any case, they were much more upright than any anthropoid ape.

Men living early in the Quaternary were capable of inhabiting shelters that they had built themselves; moreover, they were able to make and use crude stone tools. These serve as further indications that primitive men relied on intelligence rather than instinct in their struggle for survival.

Intelligence is the factor that underlies the adaptability of human beings. The marvelous organization by which ants and bees are able to survive unfavorable conditions and to build exceptional structures is admirable indeed. But their plan of construction is fixed; if external conditions change drastically, these social insects cannot adapt sufficiently to avoid extermination.

Although artifacts show a general progressive increase in perfection and adaptability, which in turn records an increase in skill and intelligence among the people who made them, progress was made at quite different rates in different parts of the world. This is known partly through dating of artifacts and skeletal remains both by means of fossil mammals preserved with them and by the

5

HOMO ERECTUS—Numerous fossil skeletons of primitive men have been discovered in China and southeast Asia, particularly Java. These men were originally given the generic name *Pithecanthropus*, but subsequent studies indicate that they were not remarkably different from modern men (*Homo sapiens*); therefore, they have been given the specific name *Homo erectus*.

The drawing shows the bone structure of *Homo erectus*. This skull, reconstructed from pieces found in various places, exhibits more modern characteristics than the australopithecine skull shown in Illustration 4. The skull of *Homo erectus* was not so thick as that of *Australopithecus*, but the forehead was still practically nonexistent. The volume of the skull vault was slightly larger. Most significantly, the jaw was weaker and the teeth were smaller; prognathism was less evident than in *Australopithecus*.

identificati- f deposits in which some of the rem. occur.

During t ourse of the Pleistocene, then, intel ce (despite its relatively low level) came an element of the selection p ss, giving certain species an advan over other species. The species wi her intelligence not only could strug successfully against a hostile nature, also could partake of the benefits of mmunal or collective life. Two factor en—collectivity and adaptable intell ce—combined to produce developme t astonishing speed.

HABITS OF MO *ERECTUS* IN CHINA—Skeletal rem s of *Homo erectus* have been discovered hina, as well as in Java. For some time th Chinese representatives were identified b generic name *Sinanthropus* (Peking ma t this classification is seldom used today bones of these ancient residents of were discovered in caves, which sugg that men were cave dwellers. In any eve bones were preserved for a long time, tously covered by sediments that gradu cumulated on the cave floors as a result e hillsides above. These primitive men very archaic industry, based principally eir skill in flaking quartz. The skull spec of *Homo erectus* discovered in China ha nial capacities ranging from about 900 (about 55 in.^{3}) to about 1,200 cm^3 (abou n.^{3}), indicating that these men were decl , superior in intelligence to the australopit es.

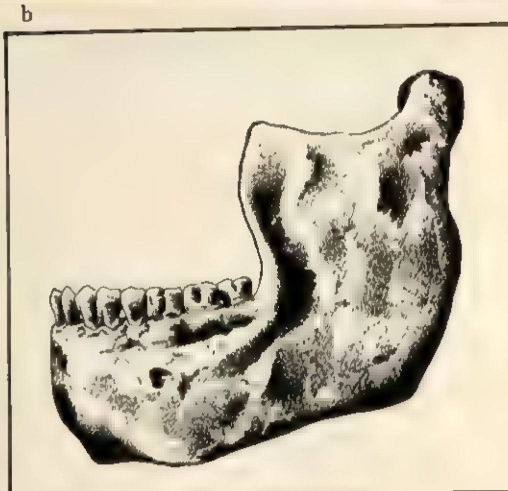
The anc hominids from China nevertheless were e ellent hunters, who had knowledge of fir and used it for cooking. Moreover, they almo rtainly practiced cannibalism and war, a they apparently had strong and active com nal ties.

6

7

a

b



HEIDELBERG MAN—In 1907, a huge jawbone was discovered in a deposit of river sediment near the city of Heidelberg in Germany; the find took place in a sand pit at Mauer, along the course of a tributary of the Neckar River. The map (illustration 7a) shows the area.

The discovery of the Heidelberg jaw provided scientists with an opportunity to observe a type of human being intermediate between the primitive Asiatic forms and those forms nearer to modern man, such as Neanderthal men. The cranial capacity of Heidelberg man was probably superior to that of the Chinese representatives of *Homo erectus*, but inferior to that of Neanderthal men. The jaw (illustration 7b) displays some primitive characteristics, along with other rather modern features, such as moderate prognathism. The name *Homo heidelbergensis* is normally used to identify the hominid with these characteristics, but some paleoanthropologists assign them to *Homo erectus*.

PALEOANTHROPIC AND NEANTHROPIC MEN | primitive and modern types

Man's evolution has taken place over a relatively short span of time—the two million years or so of the Quaternary period. This evolutionary development can be subdivided into a succession of human types. First were the australopithecines, very primitive hominids, who were quite similar to anthropoid apes, particularly

A PALEOANTHROPIC MAN FROM ITALY— This skull belonged to a primitive human being, called Saccopastore man (after the town where it was discovered), who lived about 150,000 years ago. This individual had a rather wide face, large eye sockets, a relatively low nasal aperature, and a very thick skull vault. His cranial capacity was relatively small, and his dentition was more reduced than that of *Homo erectus* and *Australopithecus*.

in their small cranial capacities. They were followed by the various representatives of *Homo erectus*, men endowed with cranial capacities at least one-and-one-half times as large as those of the australopithecines. Among them were those whose remains have been discovered in Java (*Pithecanthropus*) and China (*Sinanthropus*) and perhaps those who have been identified as *Homo heidelbergensis*.

Still later came the hominids known as Neanderthal men (*Homo neanderthalensis*). The classic Neanderthal people had cranial capacities averaging about 1,450 cm^3 (about 88.4 $in.^3$)—larger even than modern men—and they apparently descended from an earlier, more generalized Neanderthal type with more limited intelligence.

Sometime about 25,000 to 35,000 years ago, the primitive or paleoanthropic men were replaced in Europe by neanthropic men, individuals belonging to the species of modern men (*Homo sapiens*). From this time on, modern men spread rapidly to different parts of the Earth.

With the appearance of modern people, the so-called Cro-Magnon men, a superior type of civilization was launched. Cro-Magnon men were far from civilized in all senses; in fact, evidence indicates that they were extremely cruel (by our standards). Nevertheless, in their physical aspect they were completely modern. Culturally they were relatively far advanced. They were capable of performing all the activities of modern men, with the possible exception of writing. Their highly developed artistic talents were applied not only in decorating functional objects, but also in making ornaments of a nonfunctional nature. Neanthropic men made jewelry of distinctive design and style, which they wore around their necks and on their arms.

As their cultures evolved, neanthropic people came to domesticate animals and to practice agriculture. These developments gave them a certain measure of independence from the vagaries of nature. The adoption of pastoral and agricultural activities implies that neanthropic people were close observers of natural phenomena. Their high level of intelligence and their native curiosity undoubtedly led them to new discoveries, such as the fact that crops may be grown from seeds. Modern life really began with the advent of agriculture about 15,000 years ago.

In the study of human evolution, great attention has been paid to the skulls of men, because these structures bear great evidence of the separation of the human form from that of anthropoid apes. Modifications also occurred in other parts of the anatomy, especially pelvis and limbs.

The most importan[illegible]acteristics distinguishing neanthro[illegible]en from paleoanthropic peoples—e[illegible]lly the more primitive ones—are t[illegible]duction in the thickness of the sku[illegible]lt, the expansion of the cranial ca[illegible]nd the appearance of the forehe[illegible]ese structural changes provided s[illegible] for the larger brain characteristic o[illegible]rn men. Prognathism, the forwar[illegible]jection of the jaw, is much less pro[illegible]ced in modern men than it had bee[illegible] paleoanthropic people, and the den[illegible] is somewhat weaker.

Small differences n[illegible]o be noted in certain parts of the sk[illegible]ch as the posi-

CRO-MAGNON MAN—[illegible]n men (*Homo sapiens*) appeared in E[illegible] during the last (Würm) glaciation. This[illegible] belonged to a Cro-Magnon representat[illegible]hat age; in cranial capacity, it is almos[illegible]ical to the skull of a modern European. [illegible]bits very slight prognathism, the weak[illegible]tion typical of modern men, considera[illegible]l development and rather slight brow[illegible]s. Cro-Magnon peoples produced high[illegible]oped forms of art, as well as highly [illegible] stone artifacts and bone implements.

GRIMALDI [illegible] A grotto along the Mediterranean ha[illegible]d the remains of a prehistoric man [illegible] Cro-Magnon race. This man, whose pa[illegible] reconstructed skeleton is shown he[illegible] been named Grimaldi man, after the place where his remains were found. The skull characteristics of Grimaldi man are very similar to those of a modern man, with a considerable cranial capacity. The mollusks encrusted on the skull bear witness to the fact that the sea had entered the grotto several times. Near the head lies a well-preserved bone awl. Grimaldi man had been buried with great care by a people who practiced the cult of the dead.

tions of bones, sutures, nasal and frontal sinuses, and so forth. From the shape of the skull, scientists can estimate the position and presumed shape of the nose. They can carefully study the bones of the face and the areas where facial muscles had been inserted. From the forms or extensions of these areas, the scientists have been able to deduce the thickness of the muscles; from comparisons with animals and modern men, they have been able to deduce the thickness of the flesh that covered the bones. Thus they have been able to restore the face of a primitive human being. In fact, scientists have made numerous interesting restorations of the appearances of primitive men, which are displayed in many museums.

The cult of the dead apparently was not of very ancient origin in Asia or in Europe. Nevertheless, some burials dating back 500,000 to 600,000 years bear witness to the existence of such a cult. In some tribes only chiefs were buried, but in others all the deceased were interred, regardless of rank. The latter custom seems to have come into existence only in the last 100,000 to 200,000 years.

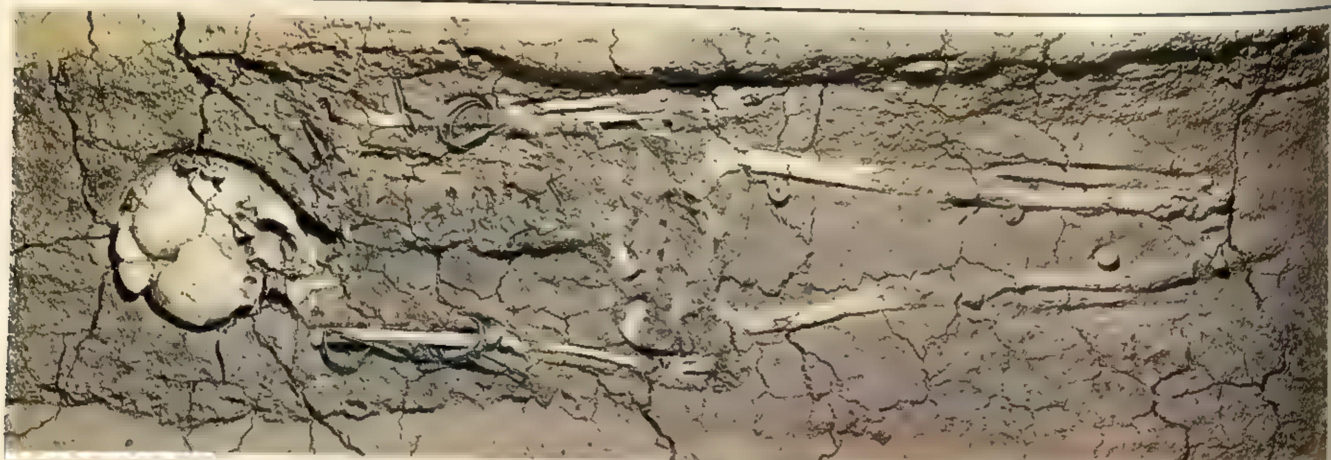
Some of the early cultures apparently had a custom of selecting very tall persons as chiefs. (The same custom has been followed in fairly recent times by certain tribes in Africa.) When a tribe lacked tall individuals, the members sometimes selected a chief from another tribe that did have tall representatives. The frequent discovery of the burial of tall people can be attributed to the fact that only the tall chiefs of certain tribes were buried, while the remains of the common people vanished because they were not interred.

The cult of the dead was practiced by both the Neanderthal and Cro-Magnon peoples, and it was done with great ritual. Near many buried bodies, scientists have discovered the remains of food, necklaces, carved stones, and other objects probably used by the deceased during their lifetimes. Practices such as these suggest that these human beings believed in some form of life after death.

Evidence yielded by tombs and the type of burial, in conjunction with such related evidence as geological stratification and contemporary fauna, is the only source of information concerning the nature and significance of the funerary remains as well as the period and race to which they should be assigned. Interment of the body together with ceremonial implements is attested at least from the Middle Paleolithic (which corresponds to the third interglacial period and the beginning of the fourth glacial period of the Pleistocene). Funerary equipment such as personal ornaments of bone and shell, amulets, and figurines increases in the Upper Paleolithic period, which was a time of *Homo sapiens* and no other man. Cro-Magnon man used red color lavishly—possibly as a vitalizing agent. The body of the deceased may have been placed in ocherous earth or smeared or sprinkled with red ocher. The flexed position was common in burials of Upper Paleolithic Europe, as it still is with many primitive tribes. Flexing and tying the body has been explained as a return to the fetal position—implying some kind of idea of rebirth.

NEOLITHIC MAN—The remains of this prehistoric man were discovered at Remedello, near Brescia, Italy. Chipped-stone tools are considered characteristic of Paleolithic cultures, while polished-stone implements are typical of Neolithic cultures. The spearheads discovered near this skeleton show the careful workmanship exercised by Neolithic peoples; the spearheads have triangular profiles that are rectilinear or rounded with absolutely perfect curves. This man dates from the end of the last or Würmian glacial age.

A PREHISTORIC MAN FROM ASIA—This skull dates from about the same time as Remedello man, but it was found in Asia (Tonkin). The skull characteristics are slightly different from those of Remedello man, but the differences may be imputed to racial variations analogous to those differentiating various population groups on the Earth today.



IRON-AGE MAN—These remains of a human skeleton came from a burial ground in Italy. They date back to the early part of the Iron Age; therefore, they are from historic, rather than prehistoric, times. The Iron Age lasted from about 800 to 150 B.C.

EARLY HUMAN INDUSTRIES | craftsmanship and art

The industries of primitive man provide a very clear index of his evolutionary development. Fossils of the last 200,000 years of the Quaternary period illustrate man's advances in rudimentary technology, religion, and even art.

Some of the early human industries are graphic in character, and are found on walls inside caves, the only place where the colors used by primitive man could be preserved. Other figurative works were preserved because they were incised; this is the case of many rock graffiti found in various parts of the world. Among the most famous are those found in the mountains of the Libyan, Algerian, and Tunisian Sahara, and at Valcamonica, Italy. These graffiti were probably never colored because they were exposed to the elements, whose effect on color was known even to primitive man.

Primitive man made these graffiti for purposes of communication or because of his belief in magic. At Valcamonica, for example, many of the graffiti indicate certain paths and roads; they were street signs and are perfectly understandable even today. The use of the arrow for marking roads dates back at least 100,000 years.

Sculpture is another very early art form; some examples have been found that illustrate the religious and magical significance given to art by primitive man. Sketches of females, for example, were symbols of fertility. They do not necessarily portray the ideal in feminine beauty, but they clearly emphasize the anatomical parts of the female body that are concerned with fertility.

The only strictly ornamental art is found in the decoration of everyday objects. Paleolithic and Neolithic man worked stone by chipping it and often he polished it; he also worked in clay to produce objects of terra-cotta. One of the most interesting discoveries of Neolithic man, terra-cotta was obtained by baking clay as is done today, but the process was far less refined and the product contained many siliceous fragments. Terra-cotta was used to make vases; on many of these, ornamental border decorations were applied. Numerous objects such as combs, pins, buckles, and so forth have also been found.

Many artifacts used for hunting have been discovered; man had begun to hunt in a more sophisticated manner. Many kinds of pointed tips were devised. Some were sharp triangular stones bound to pieces of wood for use as arrows; others were elaborate spearheads that pierced

1a

1b

QUATERNARY CULTURES—These artifacts are typical of the second period of the Stone Age. Chipped stones, dating to the Lower Paleolithic, are shown in Illustration 1a. Objects from this age are rare and are often difficult to recognize because they are such roughly shaped pieces of stone. Artifacts typical of the Upper Paleolithic are stones finished with fine chipping and polishing, as exemplified by the flint arrowhead in Illustration 1b.

the flesh of game and did not easily come out. These spearheads were bound to the tips of thin wooden shafts with plant or animal fibers. Many of these spearheads are found today in dry riverbeds in the Libyan Sahara. Primitive man also fished with arrows in the same way that some South American Indians fish today. It is hard to say whether these pointed tips were also used in warfare.

Primitive man was adept at working flint; remains of flint objects are found in many areas. Flint implements were produced only by expert craftsmen; thus, craftsmanship dates back at least 100,000 years. Utensils for a variety of uses have been found, such as [illegible] needles for sewing, and hide scr[illegible]rs. The latter were important for re[illegible]ving flesh residue from newly flayed [illegible]es so that they would not rot before [illegible] were submitted to a primitive kind [illegible]anning. Primitive man's toolbox inc[illegible]d real working tools such as wedges [illegible] splitting wood

2

PAINTING AND MAGIC—Painting undoubtedly had magical significance to prehistoric man; this can be deduced from the way his subjects are portrayed. A cursory glance at some of his paintings might indicate that primitive man wanted to depict a zoo for posterity. Cave murals exhibit a magnificent panorama of all the creatures that existed at that time. Even 100,000 years ago, the artistic ability of man was almost photographic. Bovines, gazelles, horses, rhinoceroses, wolves, bears, tigers, and so forth—all the fauna that lived alongside man during the Quaternary were painted. Often these animals were simply drawn in profile; sometimes their body structures are also visible. Many of the paintings were done in indelible colors. Primitive man used charcoal for black and ochers for other colors. These are inorganic pigments and are, therefore, very stable; thus the paintings have been perfectly preserved in those caves that were not flooded or completely closed. Occasionally, even primitive man's art materials have been found—for example, small blocks of ocher.

The magical significance is clear in some paintings. Animals are shown, alone or in herds, pierced by arrows. These paintings are believed to represent a propitiatory hunting rite or a thanksgiving rite after the hunt.

In other paintings the magical significance can only be presumed. The human hand was often painted on the walls of caves. Man covered the back of his hand with dry ocher, rested it on the cave wall, and blew hard, forming an outline of his hand on the wall. A small amount of dampness made the imprint indelible. This rite can be interpreted as an attempt by primitive man to leave his signature. It is more probable, however, that the hand, highly valued because of the great things it was capable of doing, was shown in this way to achieve greater "magical" powers.

3

a

b

HUMAN TRACES OF THE QUATERNARY—Illustration 3a shows the remains of a Paleolithic village found on Panarea, a volcanic island in the Aeolians off Sicily.

In illustration 3b are some bone and stone pendants belonging to the Magdalenian culture of the Upper Paleolithic. During this time occurred a decline in stoneworking and an advance in the art of bone toolmaking. Many assegais from the Magdalenian culture have been found; these are spears that were often serrated, and they are still used today by some primitive peoples.

During the upper Paleolithic, bone harpoons appeared. They were used both for fishing and as weapons in hand-to-hand combat. At first, the harpoons had rudimentary barbs; later, harpoons had barbs on just one side. Harpoons were further improved with a series of small barbs on both sides. A typical artifact of the Lower Paleolithic was the amygdaloid, a roughly carved stone midway between a hammer and a spearhead.

During the Middle Paleolithic, the working of stone improved considerably. It was carefully chipped, polished, and shaped into various kinds of implements such as knives, arrowheads, scrapers, and engraving tools.

and stones that presumably were used as hammers. Flint was not broken with this kind of hammer but was worked with mallets made of extremely hard woods, such as elm and boxwood.

Even today some peoples use stones after having broken them by the same techniques employed 100,000 to 200,000 years ago. For example, in some areas of Turkey, stones are still used as plowshares.

The colored paintings found on the walls and ceilings of caves in southern Europe are generally regarded as the finest flowering of Paleolithic art. Particularly interesting is the decoration of the Altamira cave, in the province of Santander, Spain, where there are unusual animal paintings that employ natural rock formations to achieve a three-dimensional effect. Standing and squatting bison, thickly outlined in black and filled in with red, are painted on bulges of the 7-foot-high rock roof so as to achieve an effect of great beauty and realism.

There is no question of the authenticity of the Altamira paintings—the cave was closed off by a rockfall. When the cave was discovered in 1868, Paleolithic bone implements were found immediately under the rock debris.

The Lascaux caves, a complex of passages and chambers on different levels located at Montignac, France, were not discovered until 1940. On the walls and ceilings are horses painted in solid black silhouette, along with horses, bison, and aurochs washed in with color or painted with an all-over dot pattern. Pigments made of oxides of iron and magnanese and iron carbonate were used to produce reds, blacks, and yellows, respectively.

At Lascaux there are friezes of horses and bulls along the lower edge of the arched roof, while the upper portion is left for paintings of larger animals. There seems to have been a consistent attempt to decorate the roof in an orderly fashion. This effect is not found in other caves, where the paintings seem placed in hit-or-miss fashion.

UNDERWATER GEOLOGY—The floor of the ocean is subjected to orogenic phenomena and erosion just as are the continents. For a long time, however, the ocean depths remained a mystery, and the organisms residing there were unknown and inaccessible to study.

Men are innately curious creatures who strive to know and understand the universe in which they live. Because of this curiosity, this compulsion to know, men have continually undertaken investigations of the unknown. In ages long past, they have ventured forth to explore both lands and seas, often at great hazard to their lives and well being. In more recent times, they have sought to discover the secrets of the atmosphere, lithosphere, and hydrosphere. Moreover, they have probed the atom, ventured into outer space, and explored the mysterious realm of the human mind.

Increasingly, men have come to apply scientific methods to their investigations and explorations, and increasingly they have come to depend on intricate and sophisticated equipment to help them find the answers to their endless questions.

Without doubt, many exploratory enterprises have been motivated by desire for wealth, fame, power, or adventure. However, many expeditions or investigations conducted for completely economic, military, or political reasons often have served to enlarge man's knowledge of his world.

Early explorations of the planet unquestionably were not launched for scientific reasons. The countless voyages in the so-called Age of Exploration certainly were not intended primarily to slake men's thirst for knowledge. But who can deny that these great adventures helped to clarify man's concept of his planet? Moreover, the voyages of the courageous sailors opened new worlds, not only for exploitation and settlement, but also for subsequent scientific investigation. It is axiomatic in science that knowledge is cumulative; men of one generation build on that which has been learned by men of previous generations. Nowhere is this more evident than in the history of the exploration of the oceans.

Ancient mariners plied the waters of the known world, seeking to exchange goods with peoples of other lands. Of necessity these sailors studied the heavens and came to depend on the stars for navigation. They learned to read the weather signs in the atmosphere, and they became acquainted with tides and currents. Modern maritime and oceanographic research is concerned with many of the phenomena that interested seafarers of earlier times. However, scientists today study the ocean in a much more systematic way, and they probe into regions never before accessible to men.

THE SCIENTIFIC IMPORTANCE OF THE OCEAN

The study of paleontology and other Earth sciences has shown beyond all doubt that the ocean has played a formidable role in the history of the planet Earth. Terrestrial sediments, in fact, are considerably less important than marine deposits, because during an equal time span the land deposits either accumulated in very limited areas or spread into hardly noticeable layers. Marine deposits, on the other hand, are quite extensive. Almost half the present land has been submerged at some time during the past; indeed, repeated marine transgressions and regressions have characterized the geological history of the Earth.

In speaking of continents, consideration must be given not only to the land that is now emerged, but also to the parts that form the continental shelves. The study of all those phenomena that take place in the shallow sea of the landmass area, therefore, is of great importance to an understanding of the paleontological history of the fossilization of animal and vegetable remains and the formation of marine sediments.

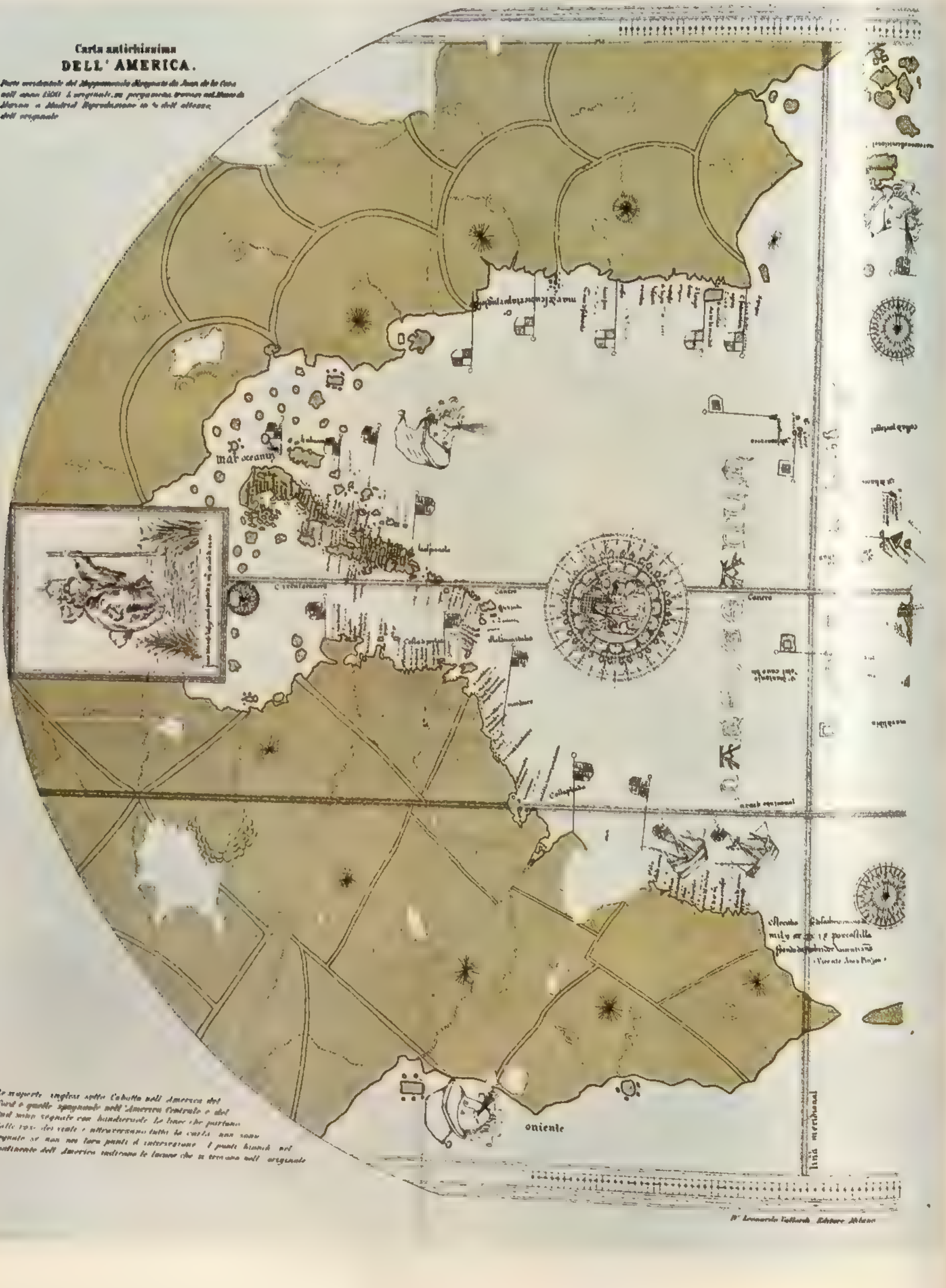
Another consideration making the study of the ocean of primary importance is the fact that the seas themselves are of great geological interest; submarine geological phenomena can help scientists clarify certain still mysterious aspects of Earth history. For example, studies of the ocean depths have led to the formulation of hypotheses concerning sea floor spreading and continental drift. Evidence indicates that a submarine mountain chain is forming in the middle of the Atlantic Ocean as a result of the upheaval of mantle rock, and the spreading of this rock to the east and west causes the separation of the continents. A phenomenon of this magnitude cannot be neglected; however, its study obviously requires large-scale and costly investigation. Phenomena such as sea floor spreading undoubtedly leave clearly visible marks, but only in the depths of the ocean where observation is quite difficult.

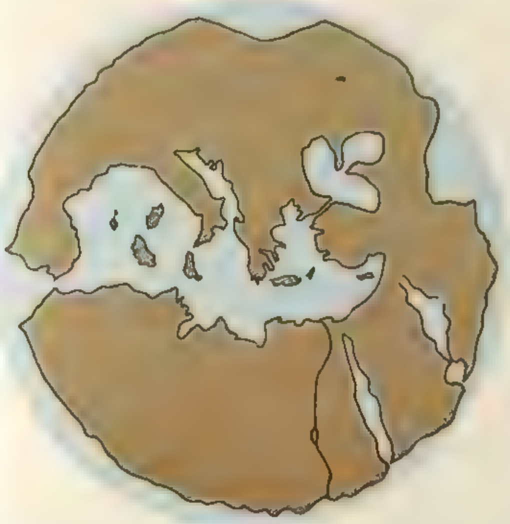
The study of the contours of the ocean bottom—at least in the detail needed to discover those small forms that indicate the presence of faults, slips, folds, and so on—is difficult to accomplish from the surface of the sea. The methods and problems typical of this research will be examined subsequently. Scientists find it important to investigate all the outward manifestations connected with the phenomena of movement: the presence of volcanoes, fractures, or other geologic features of the Earth's crust. Moreover, they must establish the course of ocean currents, and the temperature and salinity of water in different zones in the sea. The temperatures are significant, not only at the surface, but also in the depths; adequate methods of measuring these temperatures are required. The circulation of water is undoubtedly significant, because currents are responsible for the sedimentation of slime in the deepest ocean. This requires a special type of study, encompassing the entire ocean, with the aim of understanding how terrestrial sediments, carried by currents, arrive in the open sea and become deposited on the deepest ocean floors.

Furthermore, the biological phenomena that abound in the sea are not to be ignored. Apart from the theory that the first forms of life originated in the sea, it must be remembered that the sea has provided an enormous contribution to the cycle of living matter. In geological history, the mass of material that had once been part of living organisms, even though in many different cycles, is at least equal to the present mass of the land. Terrestrial organisms have made a very small contribution to this formidable process.

Figures used to describe the metabolism of land animals, such as elephants, seem enormous, because they are ordinarily compared with figures describing the metabolism of relatively small organisms, men. In the sea, on the other hand, the figures change substantially. The blue whale, the largest animal on the Earth, feeds on small planktonic animals called krill. In its lifetime a blue whale consumes about a million metric tons of plankton. This provides the reader with some concept of the quantity of living organisms in the sea. Small wonder then that scientists have discovered mountains

WORLD MAP BY JEAN DE LA COSA—This map, made in 1500, was the earliest dated map of the Americas, indicating the then recent discoveries in the New World. Jean de la Cosa, who took part in Columbus' first two crossings, was the first to map the American coastal territories, giving important information on the Atlantic coast and the Caribbean Sea.





THE PHILO ... IC IMPORTANCE OF WATER—The Gre ... losophers' conception of the world was ... important until the Renaissance. This ... by Hecateus (6th-5th century B.C.) show ... land than water. The narrow strip of sea shown surrounding the land was given the summary name Oceanus; it was deemed to border on the void, on nothingness—a frontier outside the range of man's experience and thought.

of immens ... formed by the sedimentation of th ... ls and skeletons of marine animals, ... of which individually are very sma...

From a ... tly practical point of view, the sea is ... remendous importance. For centuries, ... y people have subsisted on fish and o ... forms of marine life, and they have d ... veloped significant commercial interes ... associated with the ocean. In recent ti ... es, these interests have been extended into such diverse areas as offshore petroleum production, undersea mining operations, and desalinization and other processes involved in the extraction of minerals from seawater. Fortunately, men of many countries are now becoming aware of the need to conserve life in the sea and to prevent the pollution of this great reservoir of the planet Earth.

EARLY OCEANOGRAPHIC RESEARCH

The modern age of maritime and oceanographic exploration began toward the end of the eighteenth century, when an English expedition under the command of Captain James Cook was sent to the mid-Pacific to observe a transit of Venus across the sun. Scientists on the expedition took the opportunity to find the answer to a mystery that had remained unsolved since the circumnavigation of the globe by Magellan and his captains—the existence of a "Southern" continent. Magellan had seen land to port when he sailed toward the Pacific Ocean through the Strait that now bears his name. Cook's explorations established that this continent—now called Antarctica—does indeed exist.

Prior to that time, longitude could not be measured because the chronometer had not been perfected. Maps drawn on the basis of explorations were fairly accurate as to latitude but very inexact in longitude. Mapmakers could draw the general contours of the landmasses, but could not draw their shapes with any precision because there was no exact measurement of the longitude at which they had been observed.

Captain Cook, however, using a fairly accurate chronometer, kept a fairly accurate record of the time during his long voyage. Thus the central and southern Pacific ocean and the boundaries of Antarctica were charted with a considerable degree of accuracy. Cook was also the first to use the sounding line, a primitive but important device used to chart the depth and the extent of the continental shelf.

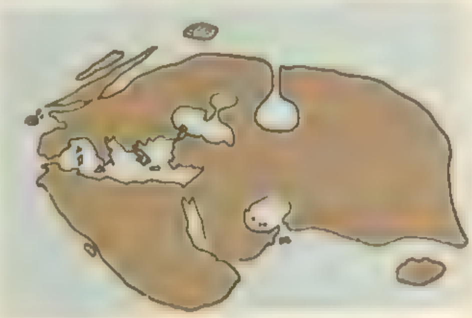
Many years after Cook's voyage, Charles Darwin set sail in a ship completely outfitted with a laboratory that enabled him to preserve biological material collected both in the sea and on land.

Many nineteenth-century ships were equipped with systems for taking samples of the water at various depths, carrying out exact soundings, measuring the speed of currents and the temperature of water, and determining the prevailing directions of winds. Such surveys had already been carried out in part by sailing-ship captains, who recorded in their logbooks the direction of winds in various regions at different periods of the year.

OCEANOGRAPHIC RESEARCH TODAY

Today, submarines that can remain underwater indefinitely have brought a significant advance to oceanographic research. These vessels have made it possible to study the bathyal depths; they can remain for long periods of time at these depths to investigate their composition, or travel along the coasts studying other problems.

One important reason for the exploration of the ocean depths has been the



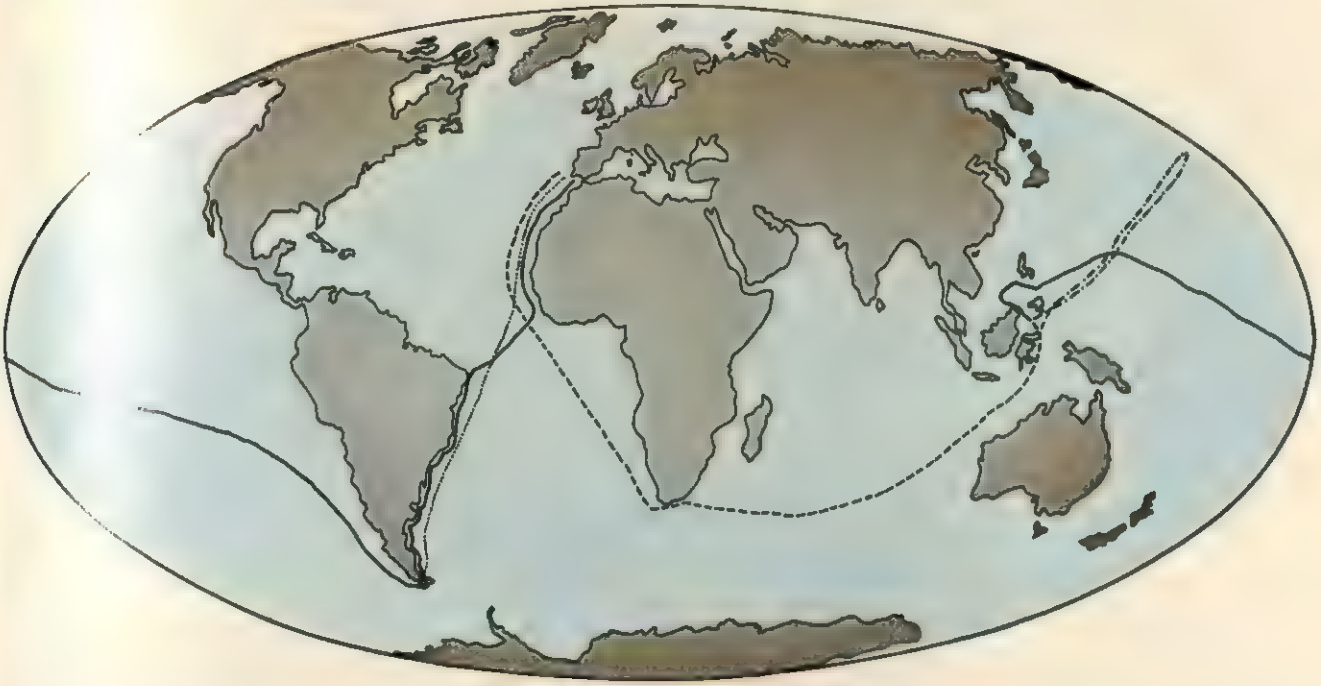
THE PHOENICIANS' DISCOVERY—The greatest navigators of the ancient world were the Phoenicians, who traveled as far as England to buy tin from Cornwall and perhaps to Denmark to buy amber, but they kept their routes secret. These talented seamen certainly did not travel for scientific reasons; nevertheless, their discoveries led to a deeper understanding of the Earth's geography, as reflected in this map by the Greek geographer Eratosthenes (275-195 B.C.). Here the oceans are shown as much vaster than they are on the earlier maps; by Eratosthenes' time, not only had the coastal areas been explored, but the seas had been crossed by ships. The map shows the British Isles, Africa, India, Norway, and the mysterious island of Thule.

THE GREAT NAVIGATOR OF THE ANCIENT WORLD—Sometime about 300 B.C. a Greek named Pytheas embarked on a voyage to discover the routes of the Phoenicians. Undoubtedly a competent navigator, Pytheas was neglected by most of the ancient historians, who regarded him as the fabricator of tall tales. In fact, he told of such incredible happenings that he was considered by many of the eminent ancient historians to be a liar. More recently, however, scholars have come to take his work more seriously. They grant that he navigated along the Atlantic coast of Spain and France and then past England, Germany, and Denmark—as this map indicates. Pytheas told of trading the stone ballast of his ship to the Danes for their amber. The Danes lived on a muddy rockless land; consequently, the rocks were valuable to them for building. On the other hand, fossil amber, which was extracted from the muddy coast, was very abundant—so plentiful in fact that it was used as fuel. Between the amber and tin ingots he acquired, Pytheas considered his voyage a commercial success.

Pytheas was not particularly careful in making measurements, and he apparently was a very gullible individual. This map indicates that he visited Iceland, which Pytheas called Thule; most modern scholars seriously doubt that he reached Iceland, although he may have ventured as far as Norway. *Thule* was a name used by many ancient geographers to identify the northernmost part of the inhabited world.

THE VOYAGES OF COLUMBUS—Sometime near the end of the tenth century A.D. the Vikings or Norsemen apparently discovered North America, which they called Vinland. This discovery followed years of westward movement on the part of the Norsemen, years in which they colonized first Iceland and then Greenland.

Several centuries after the Norsemen reached North America, Christopher Columbus set sail in search of a route to India. Believing the Earth was spherical, he intended to circumnavigate the Earth. Instead he discovered a New World, the Americas. This map shows the route he followed. Despite three subsequent trips, Columbus was never convinced that he had not reached India. His hope of circumnavigating the planet was actually fulfilled in 1522, when survivors of an expedition initially headed by Ferdinand Magellan completed a voyage around the world, thereby proving that the Earth is a sphere.



THE CIRCUMNAVIGATION OF THE GLOBE—Columbus' voyages left unsolved the problem of reaching the East Indies by way of the west; however, a New World had been discovered. Vespucci suggested the great expanse of this new land region and, for the first time, put forth the idea that the continent extended to the South Pole.

Magellan set sail to the west in the belief that he could find a passage to the spice-rich East Indies, and indeed he did find it, passing through the famous strait bordered on the south by Tierra del Fuego and entering the Pacific Ocean. Despite enormous hardships, Magellan pushed his expedition on to the Philippines, where the iron-willed captain met his death in a skirmish with some natives. Only one ship of the five that had set out returned to Spain to complete the first circumnavigation of the globe.

Tierra del Fuego, which Magellan saw on his left as he passed through the strait that now bears his name, became a symbol of the existence of a great southern land. Subsequent exploration proved that Tierra del Fuego is a rather insignificant piece of land, but that farther south a great continent does exist—Antarctica.

Many expeditions have been launched since Magellan's voyage, and many of them were intended to further the political and commercial ends of European monarchs. However, expeditions of more recent times have had as a goal the advancement of scientific knowledge concerning the planet Earth. These expeditions have been concerned with studies of currents and winds, climate, biology, geology, and geochemistry.

search for oil on the continental shelves. This search involves tedious surveying undertaken by men who work at depths of 60 to 120 m (about 200 to 400 ft) on the continental shelves. Their work has greatly advanced progress in the knowledge and techniques of underwater study and exploration.

Oceanographic research today is being carried on along many fronts. In the United States, for example, many colleges and universities have established

laboratories, departn
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of the ocean.

COOK'S VOYAGES—The dashed line traces the route followed by Captain James Cook on his voyage to the Pacific to observe the transit of Venus. The course he followed was a particularly difficult one. First he sailed down the Atlantic, which presented no great risks; when he entered the Drake Passage and crossed into the Pacific Ocean, however, he was sailing head-on into the "roaring forties" —very strong westerly winds—and navigation became very dangerous.

During this voyage Cook explored the islands

of New Zealand and
which he charted ver
voyage (1772–1775, s
eral short expedition
arctica, coming very c
apparently not landin

lay Archipelago,
ately. In a later
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vard toward Ant-
the continent but

Many g[illegible]nmental agencies are deeply inv[illegible]l in oceanographic research. Am[illegible] them are the Environmental Sci[illegible] Services Administration of the De[illegible]nent of Commerce; the Fish and W[illegible]fe Service of the Interior Departmen[illegible] Coastal Engineering Research Cent[illegible]f the U.S. Army Corps of Engineers, [illegible] the U.S. Coast Guard. The U.S. N[illegible] operates many establishments devo[illegible] to study of the ocean, including the [illegible]val Oceanographic Office at Suitland [illegible]laryland, and the Naval Research L[illegible]ratory. The Navy also administers t[illegible] National Oceanographic Data Cent[illegible]n Washington, D.C., although fin[illegible]ng of this center is provided by s[illegible]ral agencies.

Most na[illegible] with extensive fisheries have num[illegible] laboratories engaged in investigati[illegible]f the ocean. Among the countries [illegible] agencies and/or institutions dedic[illegible] to oceanographic research are Canad[illegible]pan, Australia, New Zealand, Ind[illegible]epublic of South Africa, Union of [illegible] Socialist Republics, Finland, Swe[illegible] Norway, Federal Republic of Germa[illegible] The Netherlands, France, Italy, and [illegible]at Britain.

Increasin[illegible]y, the peoples of the world have come [illegible] realize the importance of cooperatin[illegible] in their investigations of the vast and int[illegible]communicating ocean. Consequently, several international organizations have been created to further oceanographic study.

THE SEARCH FOR THE SOUTHERN CONTINENT—The first explorer to set out with the definite aim of finding the "Southern" continent was Sir James Clark Ross. The map shows the routes he followed on his voyages in the Antarctic region, where he made the first surveys that indicated the size of Antarctica (which proved to be much smaller than had been supposed). Ross made landings at certain points near the continental coast where he found breaks in the ice cliffs that fall sheer into the sea from a height of 50 m (about 160 ft).

Several groups have been established for the purpose of gathering oceanographic data necessary for the proper management of international fisheries in different areas of the world. The oldest of them is the International Council for the Exploration of the Sea, founded in 1902 and headquartered at Copenhagen, Denmark.

Another important organization, which functions as a clearinghouse for information related to hydrography and charting, is the International Hydrographic Bureau, founded at Monaco in 1921. The Intergovernmental Oceanographic Commission was established in 1961, with headquarters in the UNESCO Office of Oceanography. Still another group of importance is the International Association of Physical Sciences of the Ocean, affiliated with the International Union of Geodesy and Geophysics.

A high-water mark of scientific cooperation was the International Geophysical Year (IGY), which extended from July, 1957, through December, 1959. During the IGY scientists from more than 70 nations cooperated to carry on worldwide research in 11 areas of geophysics, including oceanography. The purpose of the IGY oceanographic program was to gain an understanding of oceanic circulation, of both short- and long-term changes in sea level, and their relationships to other oceanic and atmospheric phenomena. To conduct these investigations, 35 countries operated 70 research vessels and 225 tide stations.

THE CONQUEST OF THE ARCTIC OCEAN—The voyages of Cook and Ross encouraged further exploration, both of the geographical North and South poles and, equally important from a scientific point of view, of the Arctic Ocean. At the end of the nineteenth century, the Norwegian explorer Fridtjof Nansen undertook several Arctic voyages in a number of ships, the most famous of which was the *Fram*. In this ship, he tried to cross the Arctic in both northeasterly and northwesterly directions during different weather conditions in different seasons, covering long stretches on foot as he had done when exploring Greenland and other polar regions. On his return Nansen concluded that, in the coldest seasons, it was extremely . cult to sail these seas, except for very lim. stretches. Navigation along the northe coasts of North America and Asia becam sible only many decades later, thanks to icebreaker.

In the illustration at the broken line traces the routes of the and the parties of men who ventured on e ice when the ship was imprisoned by it. solid line shows the route followed more re ly by the United States nuclear submar Nautilus, which succeeded in sailing und polar ice cap, surfacing only a few tim t points where instruments showed that covering of ice was particularly thin. The rse followed by the submarine crossed r ns lying on the continental shelf—for ex e, between the Aleutian Islands and th ering Sea and north of this area. In the egions, the sea is relatively shallow, leav little room for maneuvering between the floor and the polar ice cap.

The *Nautilus* carried m special instruments, some of them use r the first time in maritime navigation. The rocompass, normally necessary for keepi a submarine on course, was useless in the mediate vicinity of the Pole. The boat c d two types of echo sounders—one for asuring ocean depths and the thickness e ice cap, and the other for detecting obstacles that might appear ahead. Ano nstrument was a telecamera, which mad possible to observe on a screen in th ntrol room the condition of the roof of and the points where it was thinnest. Fi , a heavy and expensive inertial navigat ystem enabled the *Nautilus* to surface afte journey under the ice cap (solid line, ill ation 10a) with an error of just one mile the long distance it had traveled wi t any external points of reference. This s type of system is now used on aircraft in m lighter, though less precise, versions.

In the illustration below ce at the top of the cross section is broken oints; these are typical of the gaps in the e cap through which the *Nautilus* was a to surface occasionally.

The voyage of the *Nautilus* pioneered modern oceanographic research, which has taken many giant steps in its wake

TH MORPHOLOGY OF THE OCEAN DEPTHS

the land beneath the sea

As earl lorers pushed westward across th rican continent, they were filled wit der at the variety of terrain th countered—broad plains, jagged m ins, deep gorges. More recently, e tion of the ocean depths has show t its terrain is every bit as varied an ndrous.

The earliest attempts to investigate the ocean depths were made by the ancient Greeks, who speculated that, based on principles of symmetry, the marine floor must have more or less the same appearance as mountain reliefs on land. These early oceanographers were on the right track, but had neither the technology nor the equipment to glean any more than a vague idea of the morphology of the ocean depths. Today it is known that the ocean floor is flat in many regions and very uneven in others.

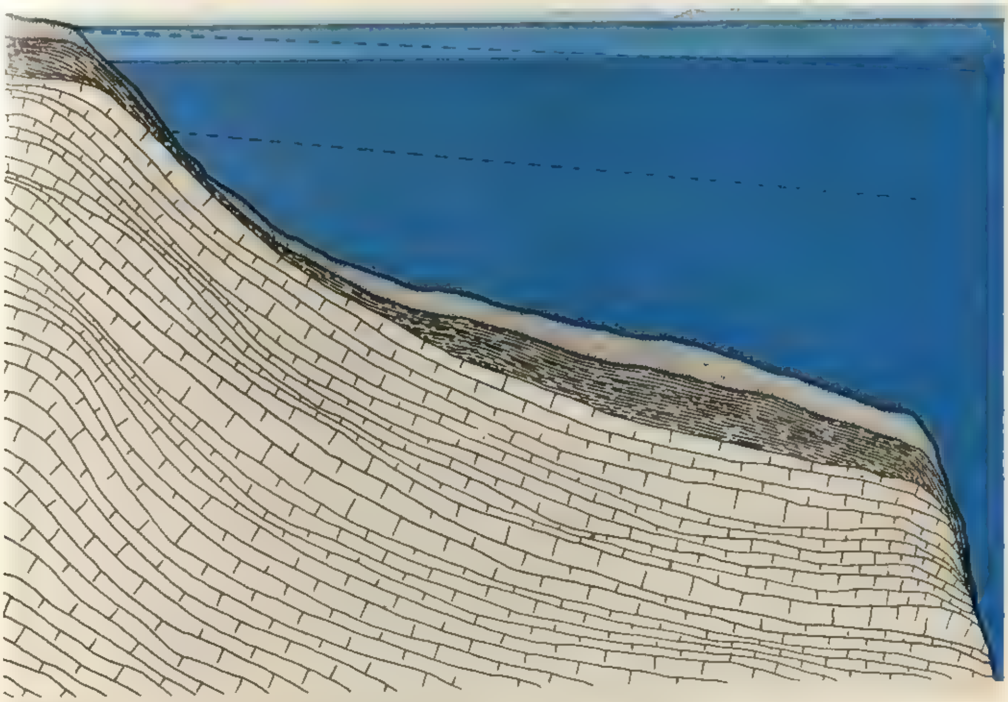
Early navigators in coastal, river, and lake waters always faced the danger of running aground in shallow areas. They

THE SUBD NS OF THE MARINE DEPTHS AND THEIR ATION TO THE GEOLOGICAL CHARACTE ICS OF THE LITHOSPHERE— This cross n shows the percentages of oceanic re t various depths. Just under 10 percent sea is less than 200 m (about 650 ft) dee s the continental shelf. Most of the geo history of sedimentation has taken plac this shelf. Next is the continental sl s region decends sharply toward the region. The slope has a gradient of to 1/20—as steep as that of mountain uch as the Rockies, the Alps, the Andes e Himalayas. The continental slope enc pth of about 3,500 m (about 10,000 ft) the abyssal zone, which makes up f the ocean depths—about 75 percen varies between 3,000 and 6,000 m (about 9,800 and 19,600 ft) in depth. Trenches—which descend to over 10,000 m (about 33,000 ft)—make up the smallest percentage of the marine depths.

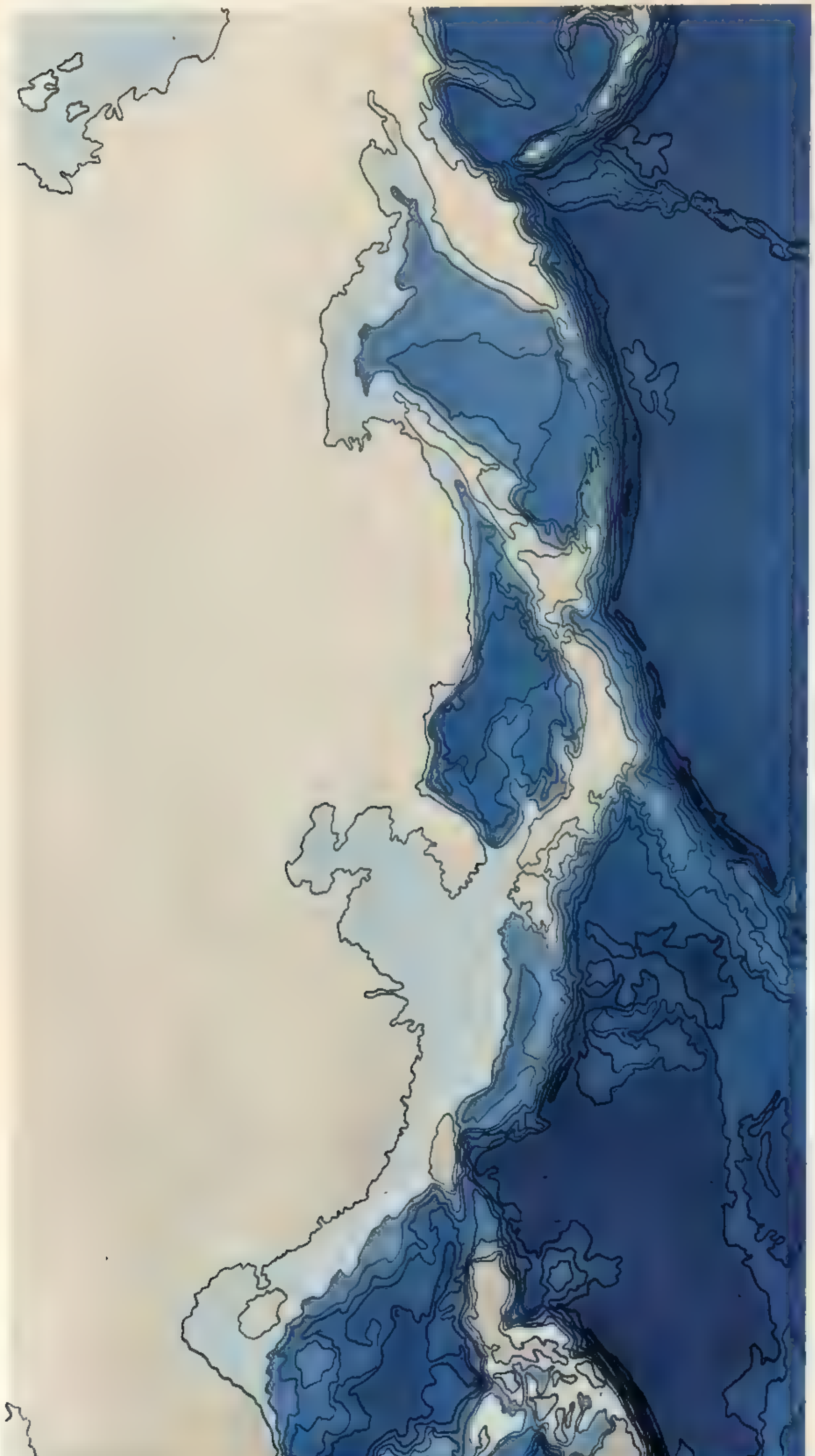
The cross section also shows the depth to which sunlight penetrates. The photic region, near the surface, reaches to about 300 m (about 980 ft). The deeper, lightless zone is called the aphotic region. The absolute limit of light penetration is about 700 m (about 2,300 ft), but sunlight in the last few hundred meters has no influence on the life of the sea.

Another subdivision of the ocean depths is based on temperature. From the surface down, the mesopelagic zone has an isotherm of over 10° C (50° F), the bathypelagic zone from 10° C to 4° C (about 39° F), and the abyssopelagic zone below 4° C.

Various factors influence the salinity of the sea, its gas content, the life it can support, and the movements of the deep waters. The continental shelf and the continental slope correspond to the continental sial masses, and form a block of fairly light rocks that, according to the theory of isostasy, float on the more dense and fluid rocks of the mantle. Below the abyssal zone, the thickness of the Earth's crust is only 5 to 10 km (about 3 to 6 mi); beneath the continents the crust is 30 to 60 km (about 19 to 37 mi) thick. These depths are in immediate contact with the rocks of the mantle, where in both past and present geological ages intense phenomena of magmatic ascension have taken place. Magma is sometimes effused over the surface of the ocean floor by intense volcanic activity.



THE GREAT ASIATIC TRENCHES—The best known of the great oceanic trenches are those along the western coast of the Pacific. They are markedly elongated in form as they follow the arcs of island chains curving from north to south. The exception is the Hawaiian chain, which lies mainly in an east-west direction. The trenches separate the island chains from an almost flat ocean floor about 4,000 to 5,000 m (about 13,000 to 16,000 ft) deep—the mean depth for all oceans.



used a primitive kin[illegible] sounding line—a long, slender stick t[illegible]as lowered into the water at the shi[illegible]w. If the stick did not touch bottom[illegible] ship could proceed safely; otherw[illegible]t moved only with great caution, o[illegible]hanged course.

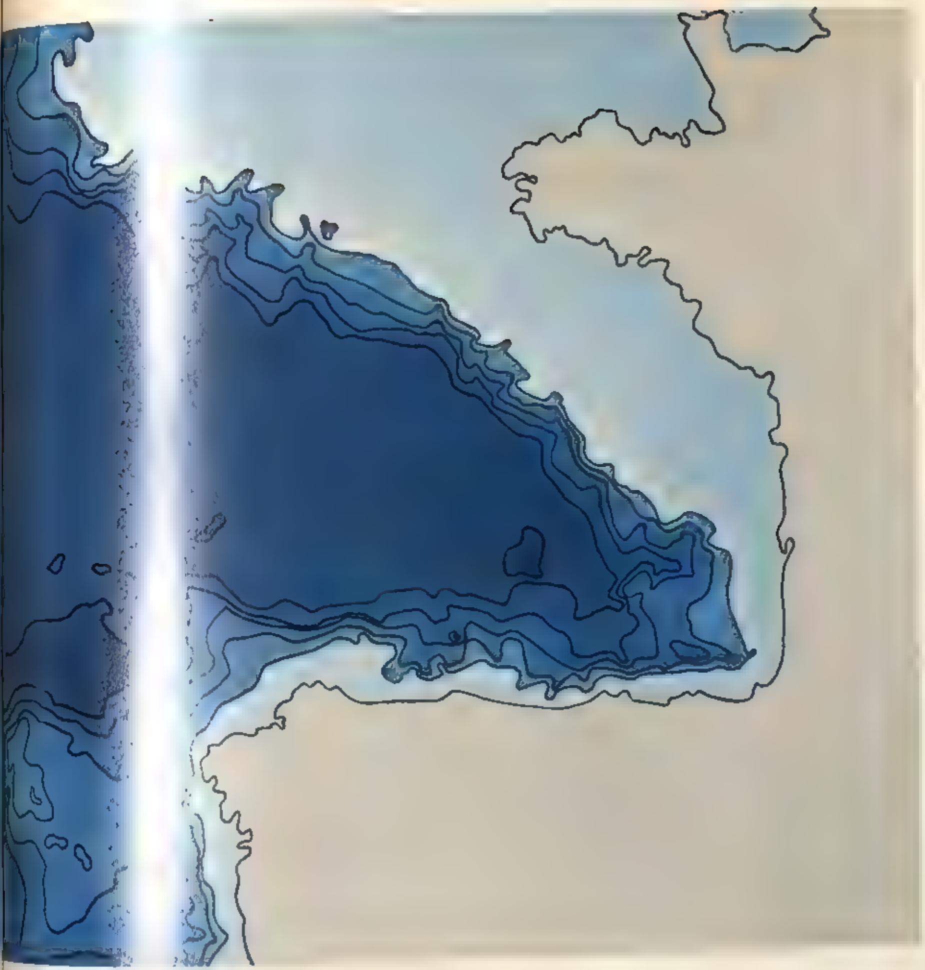
This primitive syst[illegible]ontributed little to knowledge of the [illegible]phology of the sea depths. It was [illegible]until the eighteenth century tha[illegible]ual measuring techniques were intr[illegible]ed and systematically used. A hea[illegible]on weight, tied to a relatively slend[illegible]rd wound on a winch, was lowered i[illegible]e water. When the weight hit bott[illegible]he winch was stopped and the cord [illegible]diately wound back while its exac[illegible]gth was being measured.

These soundings [illegible]aken in waters of limited depth; in t[illegible]ginning, 600 m (about 2,000 ft) was [illegible]aximum depth that could be measur[illegible] a 1773 voyage toward the North [illegible] Captain C. J. Phipps (later Lord M[illegible]ve) succeeded in sounding a dept[illegible]bout 1,200 m (about 4,000 ft). H[illegible]nding is still marked on the Engli[illegible]niralty charts, which carry all impo[illegible] soundings.

Most of the sound[illegible] taken by this method involved an [illegible]nt error: the cord used to lower th[illegible]ight undulated according to the direc[illegible]f the currents at various depths, and [illegible] measurements were thus greater tha[illegible]y should have been. Captain James[illegible]s, the British explorer, partially s[illegible] this problem by placing the sounding winch on a boat that was steadied with respect to surface currents and winds. While this system was not perfect, Ross was the first (around 1840) to obtain an accurate measurement of a great ocean depth, about 4,500 m (about 14,800 ft).

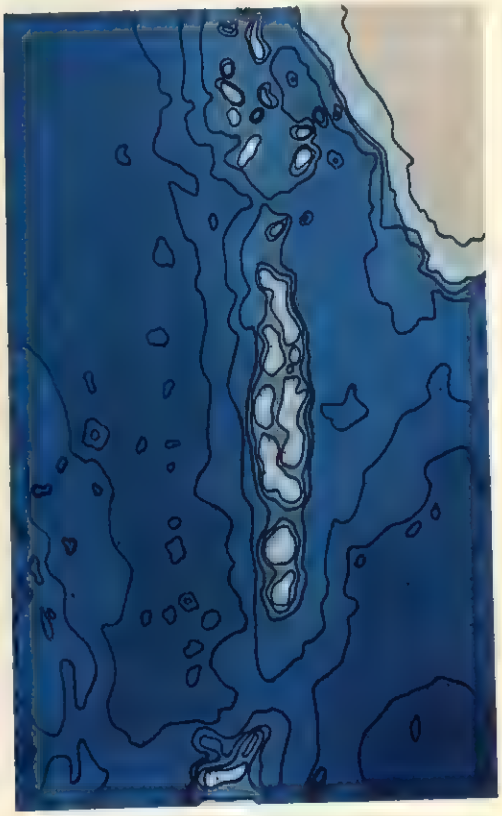
Today, the ocean depths are sounded by very precise methods. Echo-sounding devices measure the depth of the ocean by transmitting sound impulses to the sea bottom. The sound "bounces" back to the echo-sounding device; the time required for travel of the sound to and from the sea bottom yields an accurate indication of both the depth and contour of the sea bottom.

The chief morphological features of the ocean depths differ greatly from their



BETWEEN THE CONTINENTAL SHELF AND THE ABYSSAL ZONE—This chart of the Bay of Biscay shows the typical form of the slope separating the continental shelf from the abyssal zone. In this zone, reliefs stand out; they have no particularly significant shapes, but are generally found as isolated peaks. The continental slope is cut by numerous valleys.

SUBMERGED RANGES—Typical of a submerged range is that of the Maldives, which lies under the Indian Ocean in an exact north-south direction. Another very extensive north-south range occurs in the Atlantic Ocean.



dry-land counterparts. The continental shelf represents the immediate continuation of the terrestrial continental block. Outside the shelf, the depth increases abruptly and, at the greatest depths, the sea floor is generally flat and very broad. On the ocean bottom are many trenches, usually flanked by large island groups. These trenches are the deepest parts of the ocean—often well over 10,000 m (about 33,000 ft).

The deepest known places in the ocean all are in the Pacific, and there is a singular uniformity in their maximum depths. In the North Pacific, a sounding of about 10,300 m (34,060 ft) has been obtained in the Kuril-Kamchatka trench; about 9,815 m (32,180 ft) in the Japan trench; about 10,035 m (32,900 ft) in the Mindanao trench; and about 11,000 m (36,198 ft) in the Mariana trench. In the South Pacific, the Kermadec trench has yielded a depth of about 10,000 m (32,790 ft) and the Tonga trench, about 10,706 m (35,430 ft). These trenches are not circular basins but elongated V-shaped grooves. They closely parallel lines of active volcanoes, which in most cases rise above the surface as a curved line of islands.

In the North Atlantic, the deepest sounding, about 8,387 m (27,498 ft), is in the Milwaukee Depth north of Puerto Rico. Similar to the Pacific trenches, it points to a common cause. One hypothesis with considerable support is that these deeps represent areas of the Earth's crust where the sea bottom is folding downward in response to convective movements in the liquid core of the Earth; thus, the sea floor is contracting in the trench regions.

THE STUDY OF THE OCEAN DEPTHS | measuring underwater terrain

In the days of Christopher Columbus, the oceans' breadth was an unknown and mysterious quantity. For centuries thereafter, the land beneath the sea was equally unknown and mysterious. Not until 1872, when the English ship H.M.S. *Challenger* made a four-year voyage around the world taking numerous soundings, did any prolonged scientific attempt to plumb the depths of the oceans take place. The data collected on this voyage were incorporated into the first reasonably accurate bathymetric charts.

Today, exact measurements of the ocean depths are made. A great deal of knowledge about the abysses has been gleaned by a variety of methods, employing a number of sophisticated modern instruments.

Of all the tools available, the most valuable is the sonic depth finder or echo sounder, which measures the ocean depth by computing the length of time required for a sound wave to be transmitted from the ship to the ocean floor and back again to the ship. Sound travels at a speed of just under 1,500 m/sec (about 4,900 ft/sec) underwater, so that the elapsed time even in the deepest abysses is about 12 seconds.

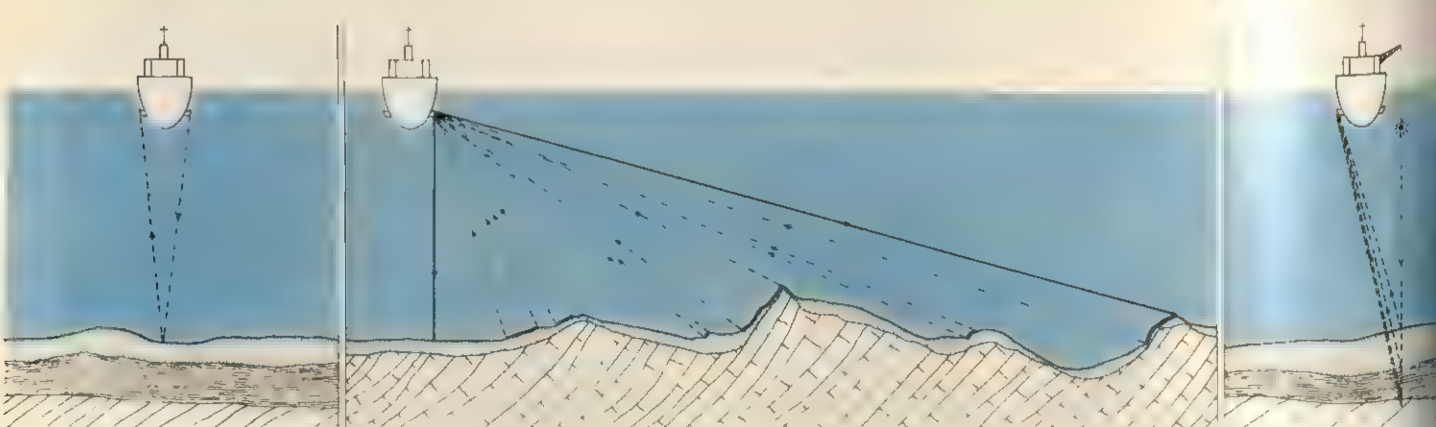
The early echo soundings seem primitive today compared with the new types of echo sounder that measure not only the depths directly below the ship, but the oblique echoes in the immediate area. Such a wide-area sounder accurately charts all the deeps, shelves, and elevations within its range.

Another important instrument makes it possible to determine all the discontinuities between the various sediments, both recent and old, below the bedrock of the ocean floor. This is accomplished by refractive seismic waves produced by an underwater explosion originated from a ship.

These methods are made all the more valuable through direct observation by devices that are lowered into the depths. These devices can col[...] specimens and take color photogra[...] Bathyscaphes, equipped with powe[...] lighting equipment, have carried m[...] deep as 10,000 m (about 33,000 ft) [...] direct observation and photograp[...] Many such devices are used for s[...] and submarine salvage.

Divers using self-c[...] ed underwater breathing apparatus [...] BA) are engaged in oceanogra[...] studies. Skin diving scientists hav[...] covered rivers of flowing sand on [...] ocean floor off Cape San Lucas, Me[...] and stalagmites and fossils of prehist[...] human and animal bones at the bott[...] of Silver Springs in Florida. Scuba di[...] also search for hulks of ancient wr[...] d sunken treasure and artifacts i[...] of the oceans and inland waters o[...] world. Rapid development of unde[...] er photography was an important de[...] pment that followed the introducti[...] f SCUBA diving. The diver, th[...] thyscaphe, the mesoscaphe (a ship [...] mid-depths),

1



ECHO SOUNDERS—This illustration shows the three main types of soundings that can be obtained by echo sounders.

Illustration 1a is a simple echo sounder consisting of a transducer attached to the hull of the ship; the transducer sends out a number of sound pulses that are reflected back to the ship, where a second transducer measures the elapsed time. Inasmuch as the speed of the sound pulses is a known quantity, the exact depth of the sounding can be immediately computed. The echo sounder's operation is entirely automatic, and indications are given on each revolution of the dial.

Illustration 1b is a similar but more sophisticated version of the echo sounder in Illustration 1a. This instrument, a lateral sounder, sends out a powerful signal in an oblique direction with respect to the ocean floor. These signals, which cover a wide area surrounding the ship, feed back those sounds that strike irregular surfaces. Charts can be prepared as the ship is under way.

Illustration 1c shows a method that utilizes underwater explosions to produce seismic waves. The shock waves penetrate the underwater sediment and rock, sending back an accurate picture of rock strata below the ocean floor. This technique is often used by oil prospectors.

and small research submarines have made it possible for man to conquer the various depths of the sea. The bathyscaphe has taken him down to the greatest known depths, the atomic submarine has enabled him to pass beneath the polar ice cap, and small submarines have taken many scientists underwater to introduce them at first hand to the environment that they wish to study.

With the aid of modern technology, man has learned more about the oceans since 1940 than he had in the preceding 2,000 years. The intercommunicating nature of the ocean has generated a number of international organizations devoted to furthering its study. Many nations and their industrial sectors have developed and put into use sophisticated oceanographic technology. The National Oceanographic Data Center, administered by the U.S. Navy but financed by several agencies, was established in 1960.

ECHOGRAM OF AN UNDERWATER PEAK—Although the underwater peak rises 1,600 m (about 5,200 ft) above the ocean floor, it is still 540 m (about 1,770 ft) below the surface of the water and is, therefore, no threat to navigation. In many other areas of the world, such underwater peaks rise much closer to the water's surface and are a hazard for ships. For this reason, bathymetric charts are of great importance to marine navigation.

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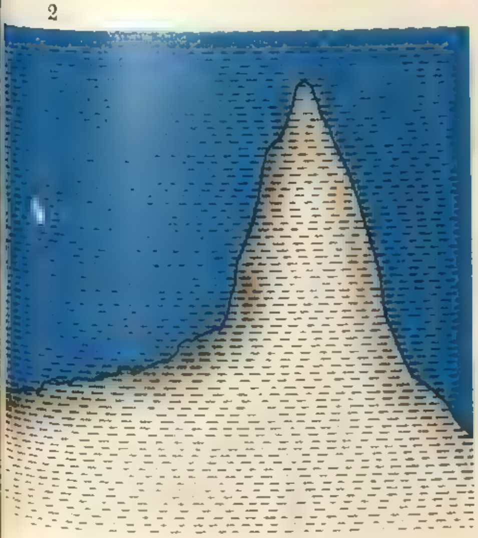

3

THE BLACK MUD CANYON—A detailed underwater map such as this could only have been obtained by echo sounders. The map is of an area southwest of Brittany off the coast of France. The canyon is named after the dark sediment that covers the deep furrows that cut across the flank of the continental shelf where it descends toward the abyssal depths. Satisfactory explanations for many such underwater phenomena have not yet been found. An entirely new geomorphology has been created to study the underwater world.

THE GEOLOGY OF THE OCEAN DEPTHS | underwater ranges, abysses, and shelves

Geology is an old science, but only in the past few decades have the tools for meaningful exploration of the ocean depths been invented. Much remains to be learned; enough data are not yet available to trace out the exact geological history of the lands beneath the sea.

Many samples of muds and oozes have been taken from the ocean depths. The nature and the composition of this material changes from the coastal areas toward the centers of the oceans. Most sedimentary deposits lie on the conti-

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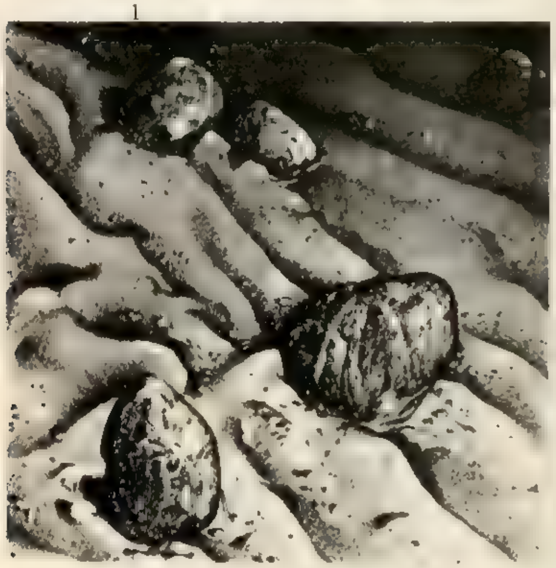
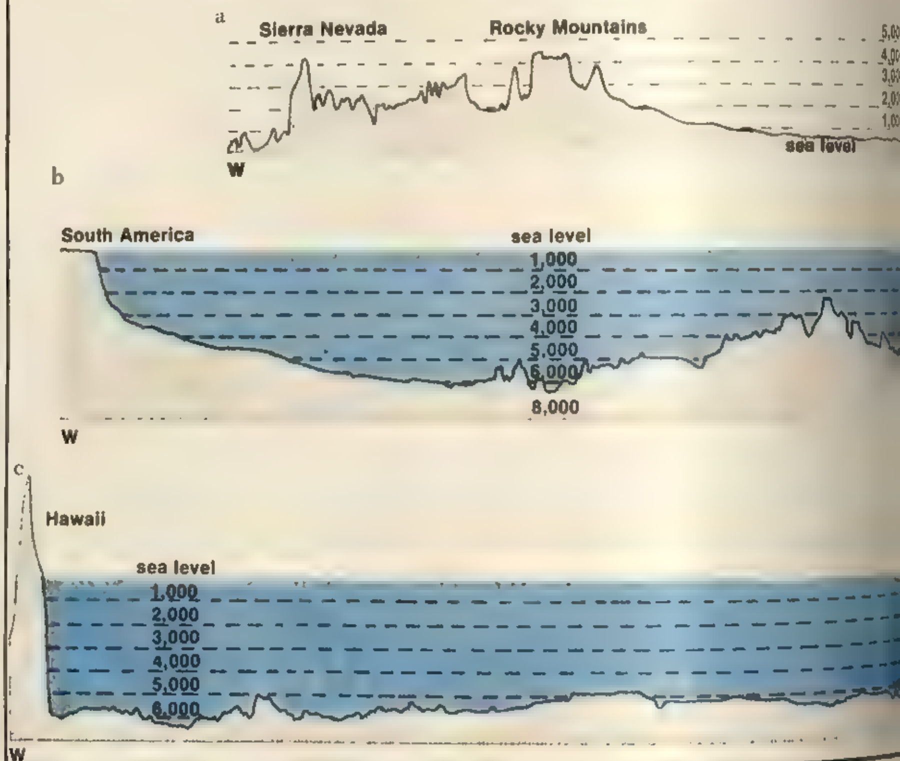


AN UNDERWATER PHENOMENON—The illustration shows an ocean floor at 3,000 m (about 10,000 ft). On the sandy floor are some large stones embedded in sand, which is rather heavily rippled. The distance between the ripple marks is about 25 cm (about 10 in.). The marks are made primarily by the deep currents of the ocean, which vary in intensity, but some of the undulations are the result of furrowing by small animals—worms or custaceans—that live on the bottom.

Currents strong enough to cause ripples of the size shown may also be responsible for erosion of rocks in the ocean depths, particularly because the erosive action is abetted by small solid particles suspended in the water. This process is not unlike that of wind erosion, but it is more effective because the particles are suspended.

2

PROFILES OF CONTINENTS AND OCEAN DEPTHS—These three profiles are: east-west cross sections of the North American continent (Illustration 2a); the central Atlantic Ocean (Illustration 2b); and the Pacific from Hawaii to San Diego (Illustration 2c). The vertical scale of each profile is one hundred times that of the horizontal, so that the heights of the peaks are distorted for effect. An observable similarity exists between the underwater ranges of the central Atlantic and the mountains of the western states. The volcanic ori-



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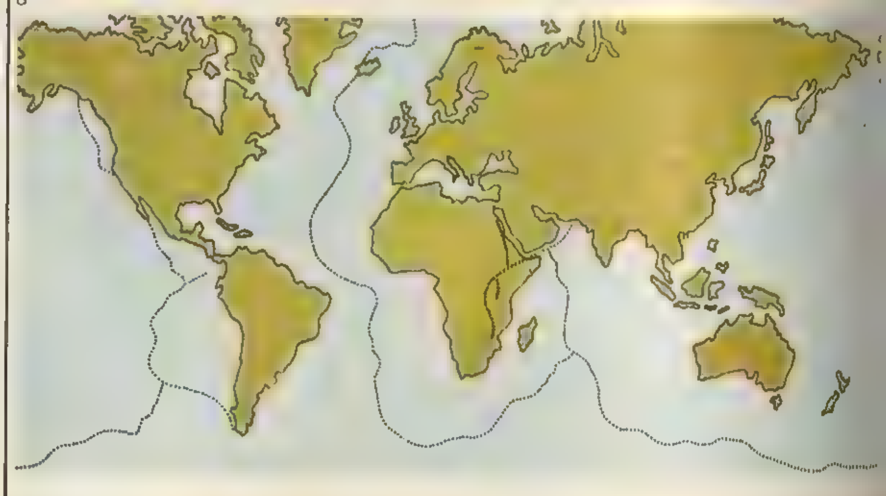
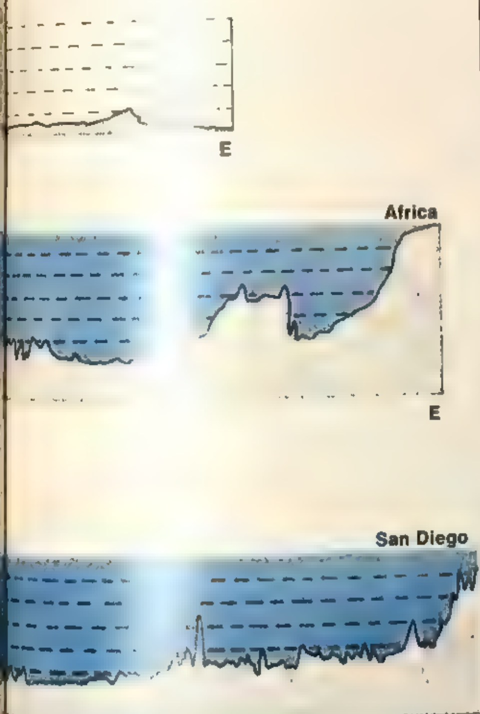


gin of the ·iian Islands is dramatically emphasized ·e sharp rise from the ocean floor.

The simila· between the continental ranges and the oc· . mountains suggests that the origins are · similar.



THE CENTRAL OCEANIC RANGES—This map indicates all the central or mid-oceanic ranges except for the range that crosses the Arctic Ocean. (The projection does not permit showing the latter.) One range closely follows the central part of the Atlantic Ocean. It continues on to the Indian Ocean, where it joins a massive range that extends approximately to the tip of South America by way of the Pacific Ocean. In the Indian Ocean, the ranges extend northward to the Gulf of Aden and right into the continental mountain ranges of east Africa. A similar course is followed in part by the Pacific ridge when it reaches North America. It is more or less merged with the coastal ranges of California and Oregon.

nental shelves close to the coast. Further out, there is not only a decrease in the quantity of deposits from the rivers, but the sedimentary particles become much smaller in diameter. This is because the action of the waves is less effective in carrying particles away from the land; only the finest and lightest particles are carried out to the open sea.

Deep within the abyssal zone, a completely different sedimentation is found. The abyssal oozes are made up for the most part of materials found in marine evolution and only slightly of materials from the continents. Near the coast, the sediment consists mainly of calcareous plankton skeletons, while in the far-out depths the skeletal material is mostly siliceous.

Abyssal sediment consists, in addition to siliceous matter, of meteoritic dust and volcanic ash. Both materials are filtered through the atmosphere and the waters to the bottom of the sea. Abyssal sediment covers most of the ocean floor, although it varies in thickness depending on the currents. The currents that flow continuously through the ocean scour the bottom completely in some parts and pile it high with sediment in others.

By mid-1970 the *Glomar Challenger*, a specially designed drilling vessel sponsored by the Joint Oceanographic Institutions for Deep Earth Sampling, had obtained samples from the ocean floor at depths of about 6,100 m (about 20,000 ft) in both the Atlantic and Pacific oceans. The evidence collected gave strong support to the theory of sea-floor spreading. It had become clear that the closer one comes to the Mid-Atlantic Ridge, the younger the layer of sediment just on top of the crust. According to the evidence, the Mid-Atlantic Ridge spreads 1 to 4 cm (up to 1½ in.) per year. Future expeditions of the *Glomar Challenger* were scheduled for the Mediterranean area in order for it to sample a region where the ocean is being downwarped as Europe and Africa converge.

FAULTS AND SLIPS—The map shows the faults in the suboceanic floor that have been discovered off the Pacific coast of the two American continents. These fault zones extend for many thousands of miles and are interconnected by perpendicular faults. Some of the faults are intersected by deep ocean trenches such as that along the coast of South America. Many geologists believe that the faults are linked in origin to the zones where submerged ranges lie.

These faults have been discovered by means of vertical and oblique soundings, followed by the taking of rock samples from along both sides of the fault. By analyzing the fossils embedded in the samples, geologists have been able to determine the extent of horizontal slippage between the two faces of the fault. The Pacific slippage was found to be widespread, suggesting that the ocean depths have undergone a much disturbed geological history.

4

5

THE MYSTERIOUS ORI... OF OCEANIC CANYONS—The stereog... shows a typica canyon cutting into the ...ental shelf. The fact that this type of f... ...on is not in a very deep part of the ... has led some geologists to believe th... origin may be due to subaerial erosion ... this area would have had to emerge se... hundred meters from its present depth ... anyon's opening into the bathyal zone is ... uished by sedimentary deposits that a... similar to those of mountain erosion co... While these deposits have the conica... ...e characteristic of subaerial deposition ... deposits in the canyon have a crowsfoo... ...n that is typical of subaqueous depositio... would seem that the canyons are partly ... ...ult of subaeria and partly of subaqueou... ...ion

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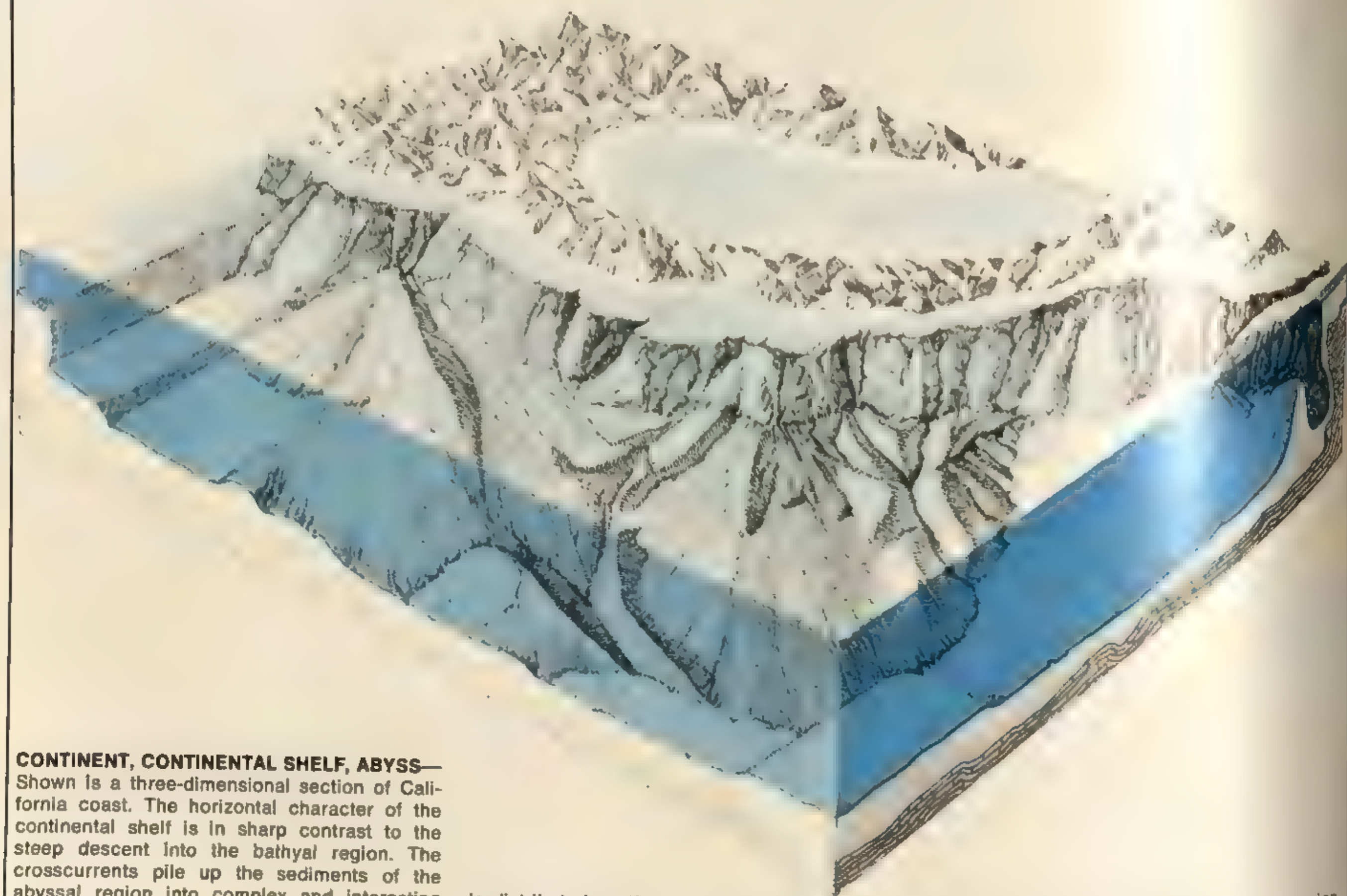


CONTINENT, CONTINENTAL SHELF, ABYSS—Shown is a three-dimensional section of California coast. The horizontal character of the continental shelf is in sharp contrast to the steep descent into the bathyal region. The crosscurrents pile up the sediments of the abyssal region into complex and interesting patterns.

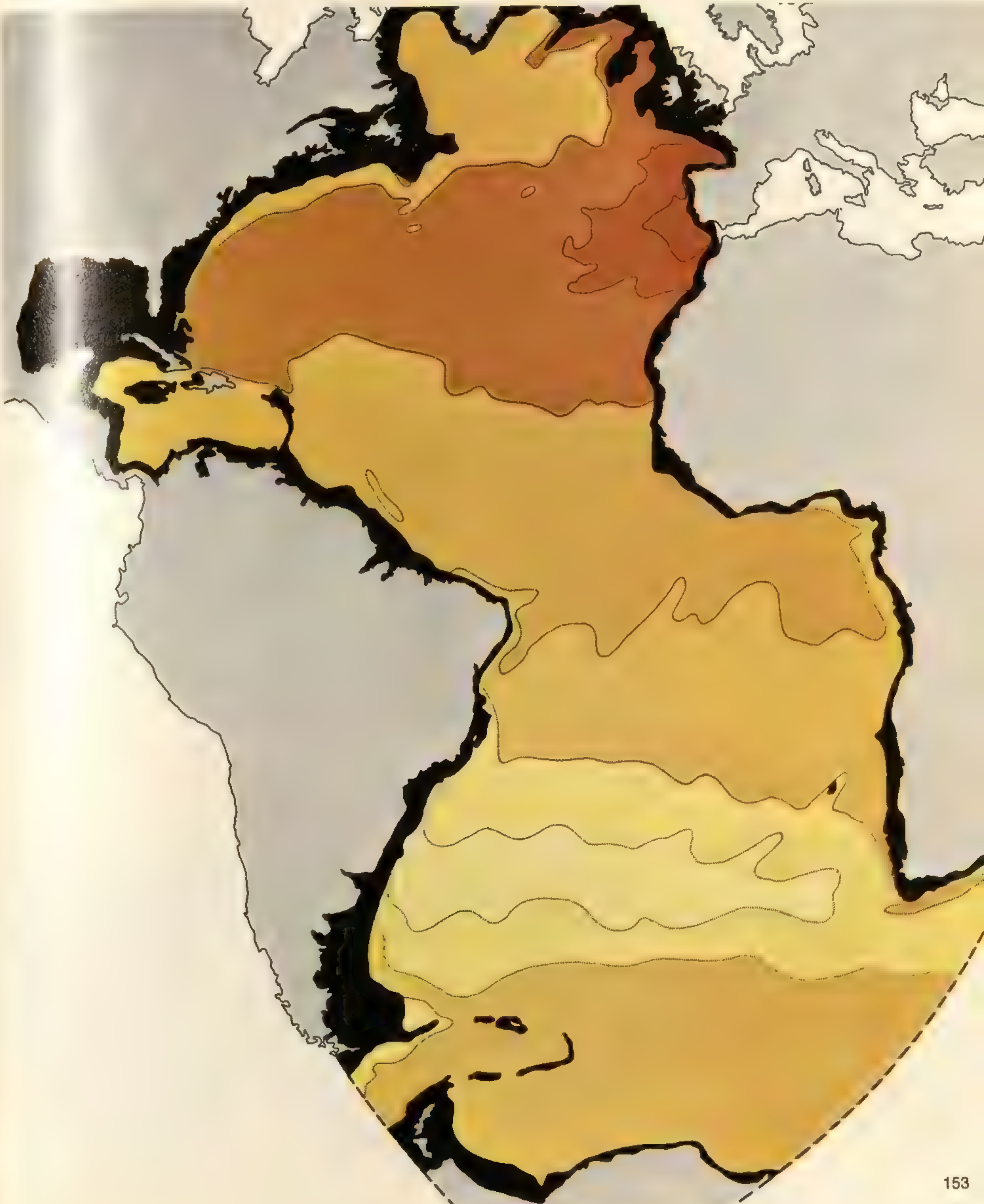
The stereograph shows how erosion detritus forms thick layers on the continental shelf. The excess detritus spills over from the continental shelf into the deeper waters below.

When the mud reaches the abyssal zones, it is distributed partly as the detritus of a subaerial cone would be and partly as the deep currents transport it. Where the detritus settles at a single point, it forms a symmetrical cone. Elsewhere, the deep currents redistribute the mud even at great distances from the collecting point. Although the shelf is narrow, only the very fine mud reaches the abyssal region.

At the mouth of the Amazon River in South America, the sediment deposited on the continental shelf causes such upheavals in the seawaters that waves of tidal force are often formed, with destructive effects sometimes fe...t far along the South American coast.

THE SALINITY OF THE SEA | an unequal distribution of salt

I



The origin of the oceans is unknown, nor is it known how the salts in seawater were deposited there. The amount of new salt that accumulates in the sea is negligible compared to the total salt content; if all the seas were suddenly to evaporate and leave the salt they contain uniformly distributed over the surface of the Earth, the resultant layer would be about 60 m (about 200 ft) thick.

The study of elements present in seawater helps explain the nature of the oceans and the origin and evolution of the currents that move in them. In 1819, an English physician lexander Marcet, made the important covery that the composition of marin lts was constant in all the oceans; whi he total salt content in grams per lit of water varied, there was no variatic n the proportion of various salts conta in each liter of

← **THE SURFACE SALINITY OF THE ATLANTIC**—In 1925 and 1926 the German oceanographic ship *Meteor* made very accurate salinity surveys of the Atlantic Ocean. The salinity chart shown in Illustration 1 (p. 153) is the product of this research.

The red-to-pale-yellow shadings on the chart show salt concentrations from a maximum of 3.6-3.65 percent to a minimum of 3.4-3.44 percent. There are two characteristic zones in the Atlantic, a zone of low salinity extending eastward from South America, and a zone of high salinity near Gibraltar.

The chart shows the salinity of the sea only to a depth of 1,250 m (about 4,100 ft). Each detail of the isohalines (the curves connecting points of equal salinity) has a precise significance regarding the origins of the salt content of seawater and the influence of the marine currents on salinity. For example, the low-salinity region (shown by the palest yellow) is caused by the arrival of water with a low salt content from the colder Antarctic Seas and from fairly deep waters. The waters of the central or equatorial Atlantic, which have a much higher salinity, infiltrate below these waters and later reappear near the surface in the Antarctic Seas.

The area of the Atlantic richest in salts is the zone of the northern temperate belt, especially near Gibraltar. The great salinity of the sea in this area is due to the outflow of very salty water from the Mediterranean, an inland sea located in a relatively hot climate and subject to strong evaporation.

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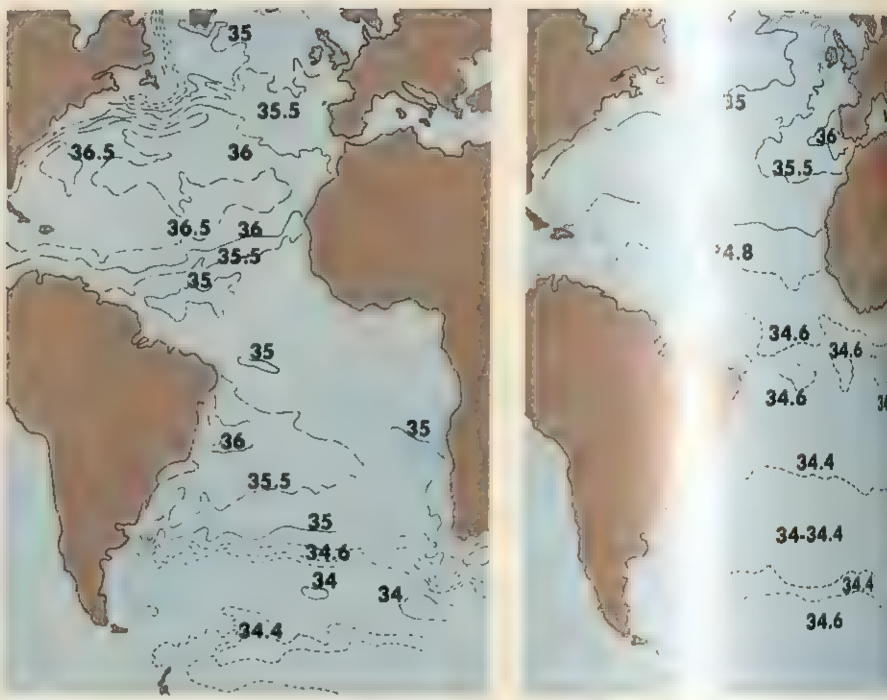
a b



THE SALT CONTENT OF THE ATLANTC DEPTHS—These three maps show the salinity (indicated as parts per thousand) of the Atlantic at depths of 200 m (Illustration 2a), 1,000 m (Illustration 2b), d 2,000 m (Illustration 2c). Although no stic change is ap-

3

DEGREES OF SALINITY OF THE OCEANS—These cross sections mark the salinity of seawater, following a vertical plain cutting across the oceans in an east-west direction. The top of these illustrations represents the surface of the respective oceans. Illustration 3a shows the salinity of the Atlantic, Illustration 3b that of the Pacific, and Illustration 3c the salinity of the Indian Ocean. The most

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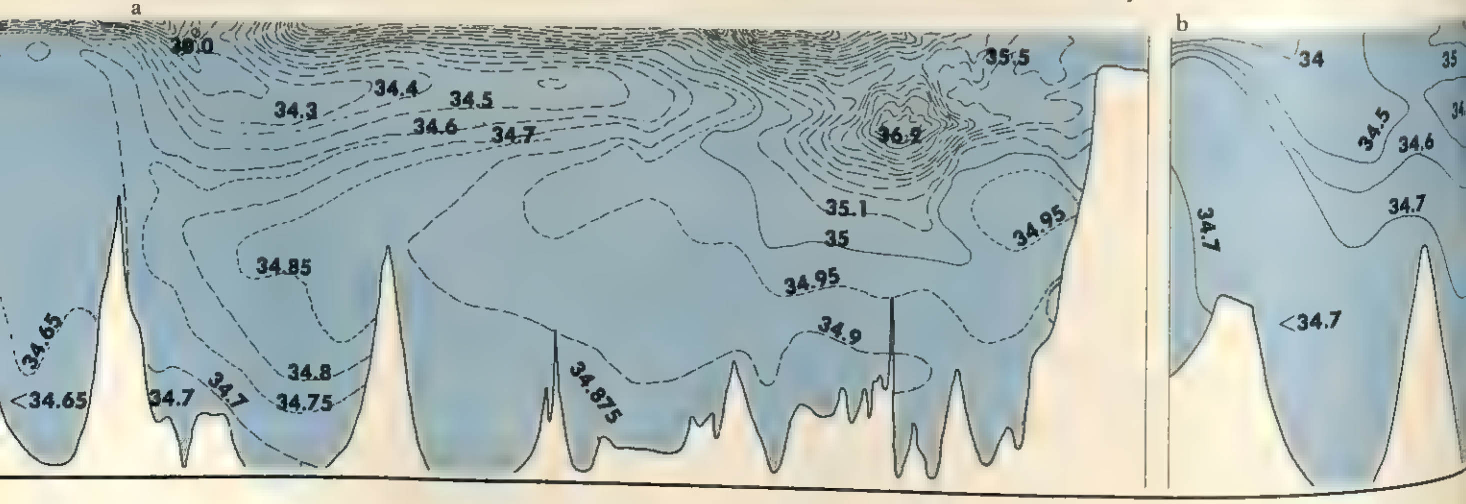
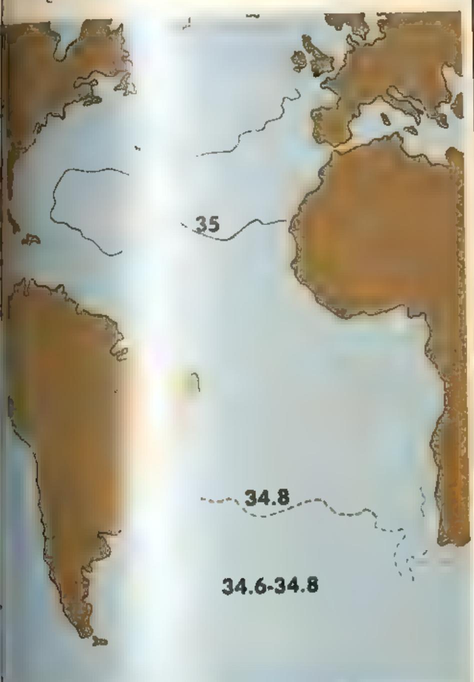


water. Ma· ·t had analyzed only 14 samples of wa· but later analyses of a large number of ·mples confirmed his findings.

Howev· the average content of salts in seawat· · extremely variable. Certain regions a. particularly rich in salts—about 37 · 41 parts per thousand in the Red Sea and slightly less in the Persian Gulf, about 35 to 40 parts per thousand. The lowest salinity is in the Baltic Sea, with only 2 to 7 parts per thousand. Also very low in salt content is the Black Sea, with 18 parts per thousand.

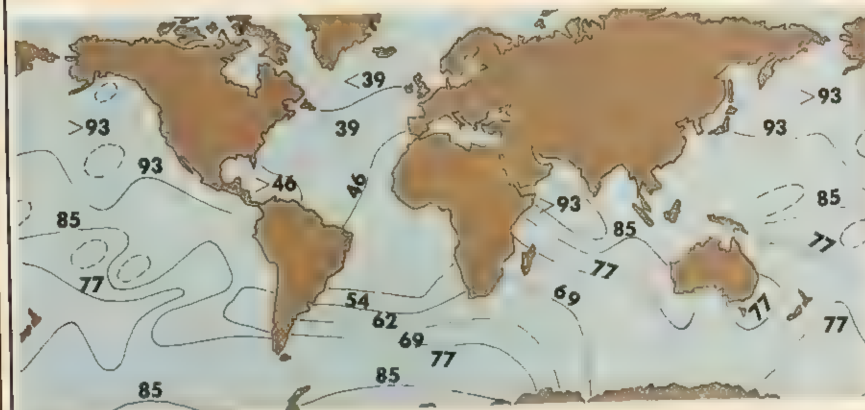
These differences in salt content can be readily explained. The salinity of deep fjords or river estuaries is low because of the slight evaporation rate and heavy precipitation in these zones, and because of the discharge into them of fresh water from rivers and glaciers. Such enclosed seas as the Red Sea and the Persian Gulf,

c



parent in the general course of the isohalines, they indicate different salinity trends at the three different depths.

4



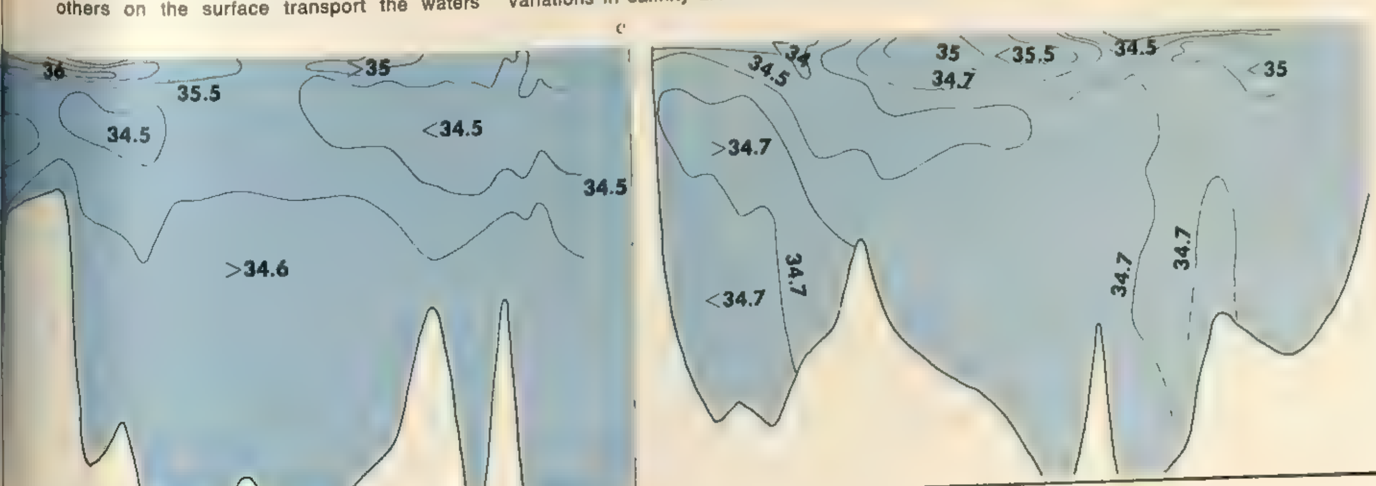
CHARTING A PARTICULAR ELEMENT—The mean salinity of the sea gives a remarkably precise indication of the movements of currents. Singling out a particular element is also helpful in the study of these movements. One such element, present chemically in the form of phosphates, is phosphorus, found in conjunction with other elements. This chart shows the curves of equal phosphate content; the figures of each isophosphatic curve give the phosphorus content in milligrams per cubic meter of seawater. The phosphate curves follow the curves of average salt concentration, but with greater variations of intensity.

which receive no inflow of fresh water, are subject to a high rate of evaporation, and are comparatively shallow; as a result, their salinity is high. Less explicable is the variation of salinity, even to a relatively small degree, in the great oceans.

A simple method is used to study the salinity of seawater. A Nansen bottle is lowered into the water and opened at a predetermined depth. When the bottle has filled with seawater, it is closed and brought to the surface. The water is re-

precise of the three profiles is that of the Atlantic. Currents in the ocean depths and others on the surface transport the waters from the different latitudes. Their locations are marked by isohaline curves. Studies of the variations in salinity are useful in determining many phenomena that take place in the oceans, such as the origin and nature of the currents.

c



moved from the bottle and a sample of it is evaporated off in the laboratory; in this way the salt content can be determined. Because of variables, however, it is not easy to make a determination of salinity directly. Determinations of the salinity of sea water for this reason usually are derived from measurements of some other property, such as electrical conductivity, specific gravity, index of refraction, or chlorinity, which yield more satisfactory results.

The study of s[illegible] helps toward an understanding o[illegible] phenomena that take place in th[illegible]ns, particularly that of evaporati[illegible]ations in salinity are also useful in d[illegible]mining the movements of currents.

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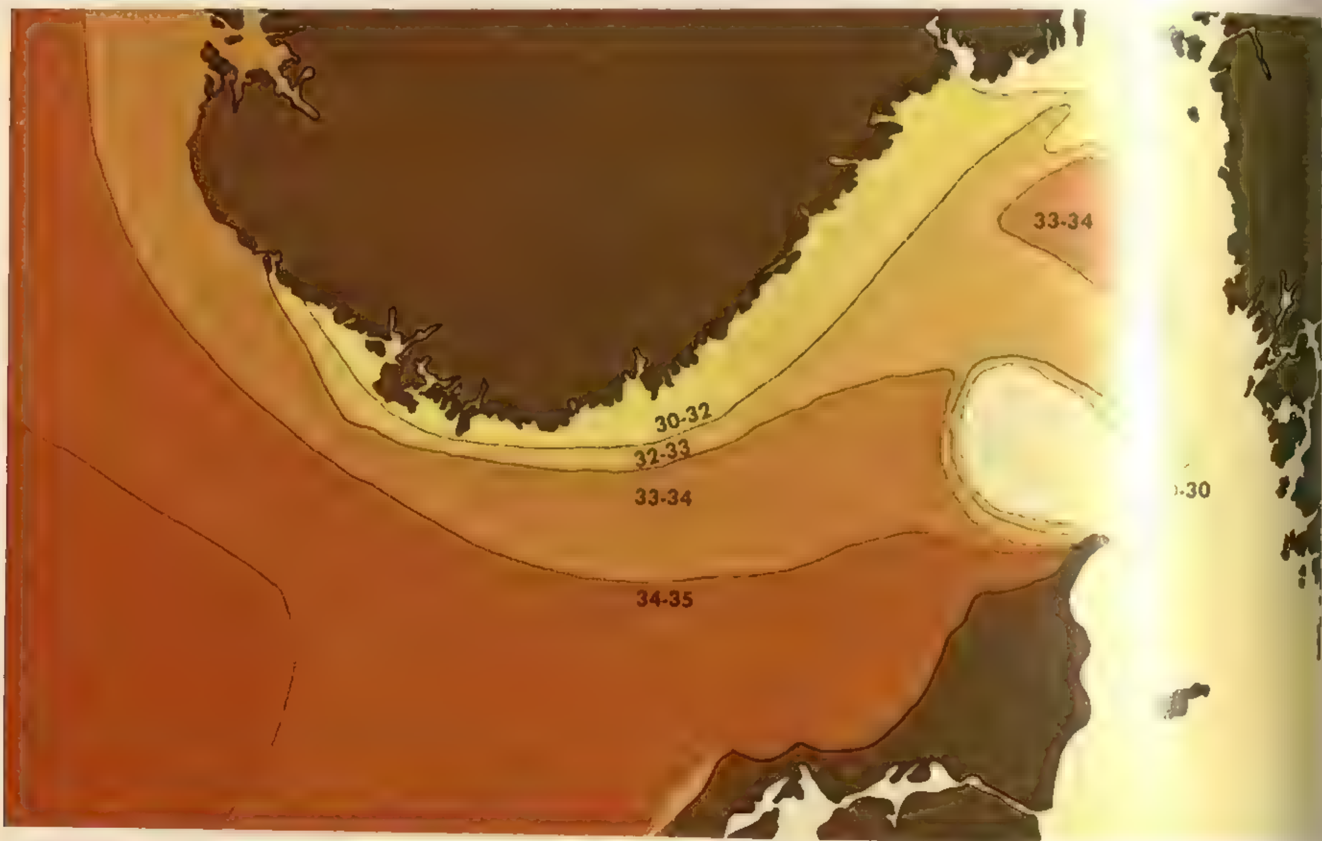


AN UNUSUAL DISTRIBUTION OF SALINITY—This isohaline chart is of the Skagerrak, where the low-salinity waters of the Baltic Sea mingle with the waters of the Atlantic, which have a much higher salt content. A number of factors account for the low salinity of the Baltic. It is subject to very heavy precipitation and very slight evaporation, and receives an enormous inflow of fresh water from a great number of rivers; perhaps most important, the numerous rivulets of meltwaters from the many glaciers in the surrounding regions all flow into it. At the Skagerrak, where large masses of warm water are transported to the North Atlantic by the Gulf Stream, a tongue of low-salinity water stretches out toward the warmer and more saline waters of the Atlantic.

This region has an extremely low salt content of less than 20 parts per thousand. In some regions of the Baltic, the salt content is even lower; these are places where there is an enormous inflow of fresh water, such as certain narrow inlets or river estuaries. Because the Baltic Sea is not very deep, even a moderate amount of fresh water brought by rain or the rivers causes great dilution. In the Atlantic, where depths are much greater, great masses of water, even with a high salt content, can be transported by small currents.

Both differences in temperature and in salinity involve differences in density, which, for different reasons, may cause horizontal or vertical currents. The variations in temperature and salinity may be very slight, but because enormous volumes of water and mass effects are involved, the total forces are huge and can produce extremely significant currents. The effects of salinity and temperature may be concomitant or antagonistic; the effects of temperature may be much more marked than those of salinity.

A typical effect is found in the Adriatic Sea, which has a very regular stratification with a variation in salinity of a few units per 10,000 as each deeper layer is reached. (The kind of stratification that exists in the seas also exists in the atmosphere, as is indicated by comparison of the distribution of air and water currents and their temperatures.) Generally speaking, adjoining masses of water with different temperatures seldom intermingle, even though they are in contact. Each mass maintains its own temperature and its own salinity.

CURRENTS AND TIDES | movements of the restless sea

The ocean [illegible]s fascinated men for countless ages. [illegible]hermen have waged a tireless but a[illegible]tionate struggle against the sea, eking [illegible] a living from the "mother of life." [illegible]nturers have braved the hazards o[illegible] known waters in search of new land[illegible] treasures. Artists have vividly port[illegible] the awesome power and majesty [illegible]ocean, and poets have described t[illegible]uty and treachery of the sea. Spo[illegible] have sought their thrills in skin d[illegible]nd surfing, and scientists have stud[illegible]e seas in an effort to learn more abo[illegible] world in which they live. Moreover, [illegible]ople everywhere have marveled at t[illegible]seless motion of the sea.

To th[illegible]e person, mention of the moving s[illegible]jures up pictures of great waves c[illegible] over the bow of a ship or break[illegible]ming against a reef. However, in[illegible] the movements of the sea are [illegible]d, waves are of little importanc[illegible]nts and tides, on the other hand, a[illegible]ficant.

CURR[illegible]

Ocean [illegible] are produced by the friction be[illegible]oving air masses and the surface [illegible]. Prevailing winds continuall[illegible]across the surface of the sea, and [illegible]ction between the moving air an[illegible] water produces ripples, thereb[illegible]ng more surface area to the wi[illegible]ncreasing the friction. As the fric[illegible]reases and the wind continues to [illegible]v, a horizontal movement of the masses of water may take place; in other wor[illegible], the wind tends to drag the water along.

Attributing ocean currents to wind drag (wind drift) alone is an oversimplification of the current phenomenon, for other factors influence ocean currents. One of the most important factors is the Coriolis force, a force produced by the axial rotation of the Earth, which deflects a moving mass from the path it ordinarily would take. Air masses, for example, tend to move from regions of high pressure to regions of low pressure. Air masses over the Poles have high pressure, and those over the Equator have low pressure; in between are alternating regions of high and low pressure. Air tends to flow, for example, from a polar high-pressure region to a subpolar low-pressure region, as well as from middle-latitude high-pressure regions toward the equatorial low-pressure area. However, the air masses do not move in straight north-south lines. The rotation of the Earth has the effect of deflecting the masses to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This effect of the Coriolis force is largely responsible for the prevailing wind patterns in the atmosphere.

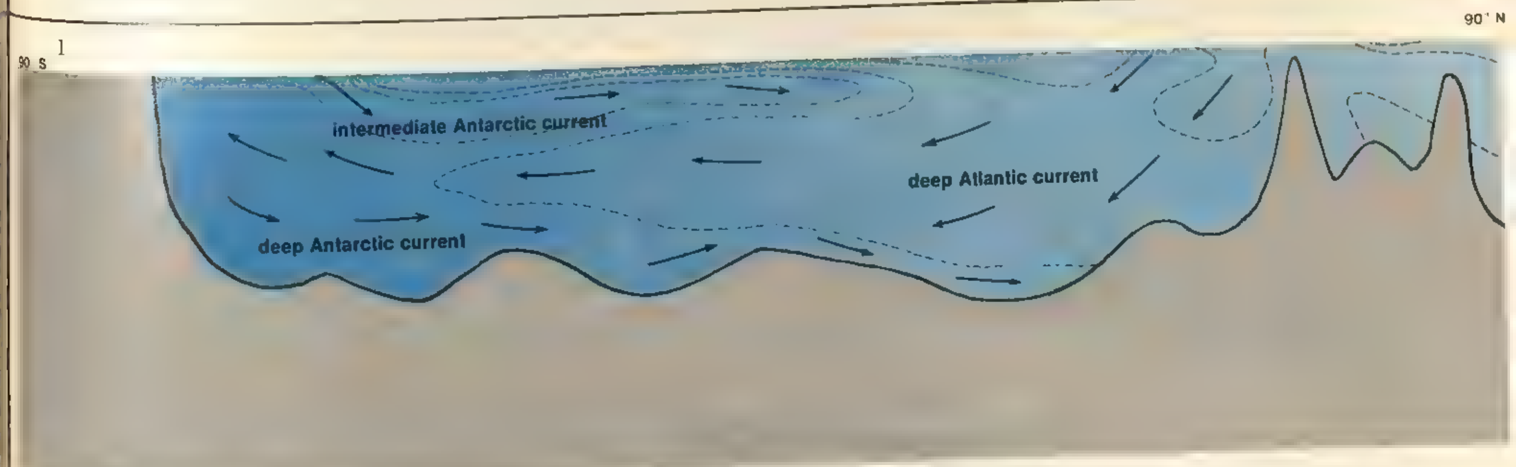
Ocean currents are also deflected by the rotation of the Earth. One might assume that wind-generated currents move in the same direction as the wind. But in the Northern Hemisphere, the water moves in a direction to the right of the wind path; in the Southern Hemisphere, the deflection is to the left of the path of the wind. Surface currents are generally deflected about 45° from the direction in which the wind is blowing. At greater depths, succeeding layers of water are deflected even further as a result of the movement of the layer above. At considerable depth, the current indeed has been deflected so much that it actually flows in a direction opposite that of the wind. The currents at different depths move not only in different directions, but also at different speeds.

Other factors affecting ocean currents include the configuration of continental shelves and coastlines and the morphology of the ocean depths. Important deviations in the directions of ocean currents may be caused by the existence of submarine mountain ranges and valleys and by variations in the ocean depth.

A general rule states that currents are stronger in the western parts of the great ocean basins than in the eastern parts of those basins. Examples of these intense western currents are the Kuroshio or Japan Current in the Pacific Ocean, the Gulf Stream in the North Atlantic, and the Agulhas Current in the Indian Ocean.

Large rivers emptying into the ocean also affect currents. The Gulf Stream, for example, unquestionably is affected by the huge volume of fresh water poured into the Gulf of Mexico by the Mississippi River and other large streams.

Still another factor is the differential heating of the waters of the world's seas. Solar radiation heats the surface waters of equatorial regions far more than it does those of polar regions. The equatorial waters consequently expand and move; the heavier polar waters sink and carry to the ocean depths quantities of oxygen, which make life in the depths possible.

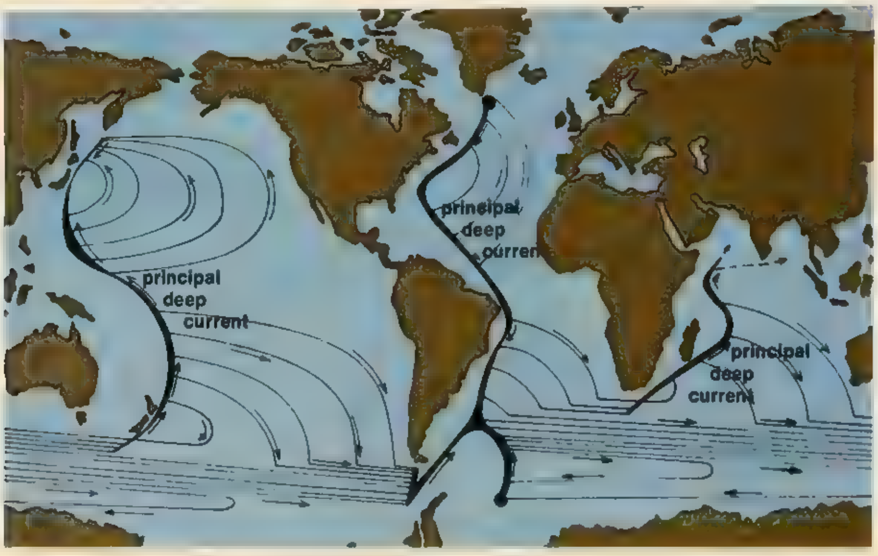


DEEP-WATER CURRENTS IN THE ATLANTIC —This illustration shows a cross section of the Atlantic Ocean from the South Pole (on the left) to the North Pole (on the right).

Much of this ocean extends to a depth of 5,000 m (about 16,400 ft). Near the Equator the surface waters move in a northerly direction, while those at a depth of about 3,000 m (about 9,840 ft) flow southward. At the greatest depths, the waters again flow northward. This diagram presents a rather incomplete picture of the movement of surface waters, but it conveys a fairly clear idea of the complexity of deep-water circulation in the Atlantic.

DEEP OCEAN CURRENTS—Most deep ocean currents are very strong and flow near the western boundaries of the great ocean basins. Smaller and weaker currents flow out of them, circulating water in two great rotating patterns in each basin—one in the Northern Hemisphere and the other in the Southern Hemisphere.

2



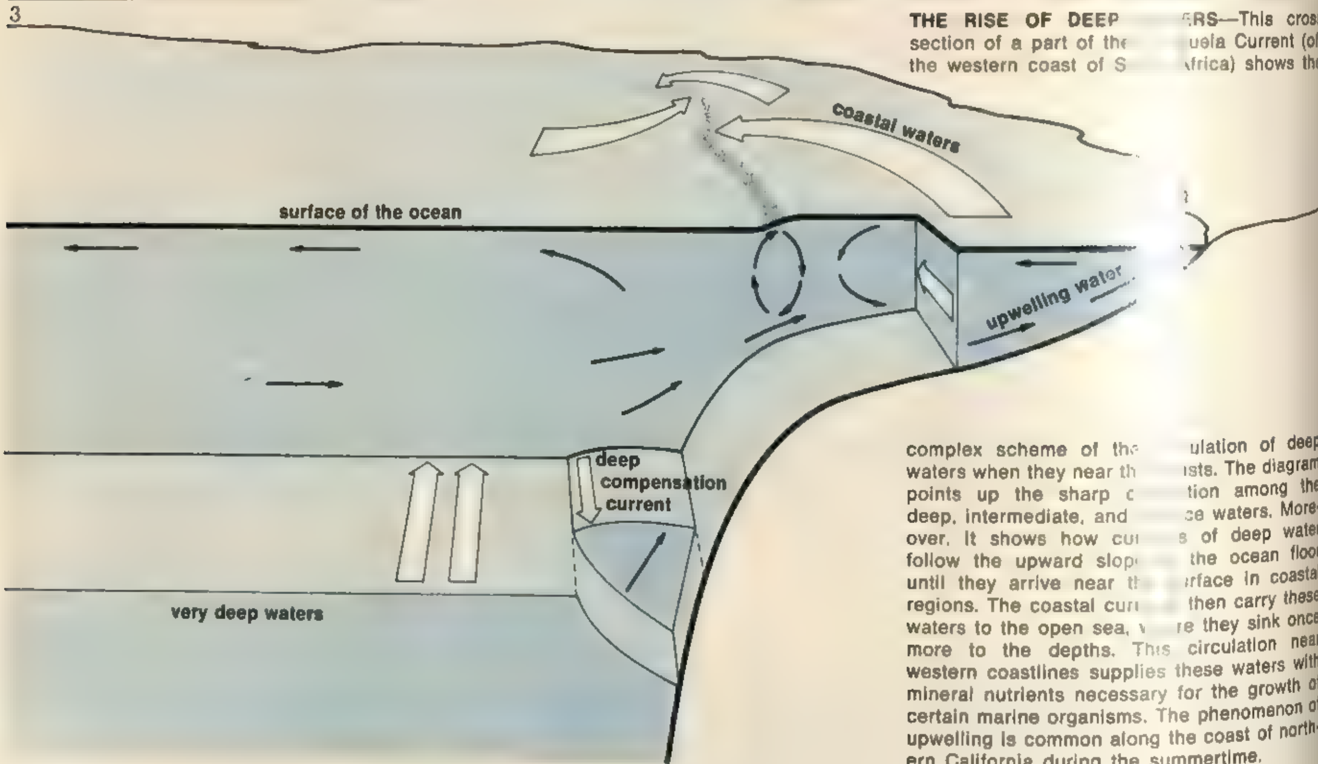
speeds less than 2 km/hr (about 1 mph). The same is true of many currents in the open sea, but at times currents can reach great speeds. Note, for example, the Gulf Stream, which reaches a speed of 8 km/hr (about 5 mph) at some points. Clearly the influence of swift-moving currents on powered vessels can be considerable; for sailing ships, the curre[illegible] were (and still are) of utmost signif[illegible]ce. A study of old charts showing th[illegible] trade routes of sailing ships indicate[illegible] that these ships often were unable to [illegible]w the shortest or most direct routes s[illegible]ly because they were forced to move [illegible]e direction of the prevailing winds [illegible] currents.

THE TIDES

The tides constitute [illegible]er type of important movement [illegible]ng the waters of the ocean. The fan[illegible] rising and fall-ing of the tides is produced primarily by the gravitational attraction between the moon and the waters on the surface of the Earth and secondly by the attraction between the sun and those waters.

The force of attraction between two bodies is directly proportional to the combined masses of those bodies and inversely proportional to the square of the distance between the centers of the two bodies. Obviously, the attraction is greatest between the moon and the particles of water located on the side of the Earth

3



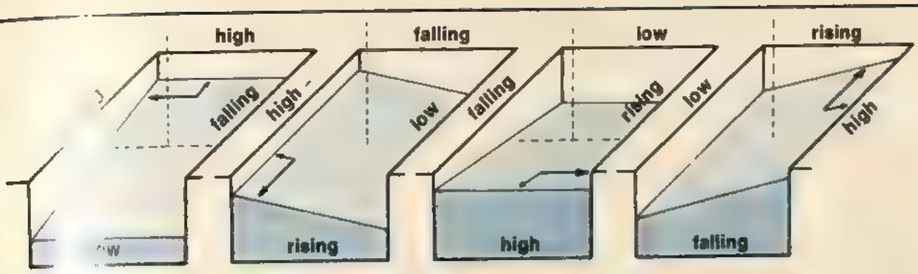
THE RISE OF DEEP [illegible]**RS**—This cross section of a part of the [illegible]uela Current (off the western coast of S[illegible]frica) shows the complex scheme of th[illegible]ulation of deep waters when they near th[illegible]sts. The diagram points up the sharp c[illegible]tion among the deep, intermediate, and [illegible]ce waters. Moreover, it shows how cu[illegible]s of deep water follow the upward slop[illegible] the ocean floor until they arrive near th[illegible]rface in coastal regions. The coastal cur[illegible] then carry these waters to the open sea, w[illegible]re they sink once more to the depths. This circulation near western coastlines supplies these waters with mineral nutrients necessary for the growth of certain marine organisms. The phenomenon of upwelling is common along the coast of northern California during the summertime.

Another phenomenon is known as upwelling. Under the influence of the wind, large amounts of surface water may be removed from certain coastal areas; this water is replaced by water rising from great depths. The rising water is rich in nutrient substances needed for the growth of plankton and, therefore, for the growth of higher forms of life whose existence depends on plankton.

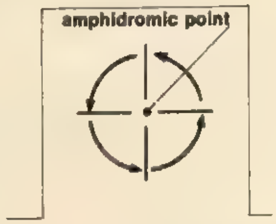
Long before scientists began to speak of water pollution as a determining influence in marine biology, they attributed to current changes the changes in the habitats of certain species of fish—such as the herring that disappeared from the English Channel and other regions of the North Sea. Indeed, the currents are of great importance to the fishing industry.

The study of currents is important, therefore, not only from a scientific point of view, but also from a practical standpoint. Ocean currents can move with considerable speed and can exert great influence on navigation. Most coastal currents and those in inland seas move at

4a



4b



SEAS A ASINS—If the Earth were covered by gle gigantic ocean with a constant de me tidal theory would be flawless. However tuality, the waters of the planet are brok p by great continental landmasses that effec ly separate the waters into basins. The stru re of these basins strongly influences tides.

The di ams in illustration 4a show how water behaves when it is confined within a narrow basin. Depending on the position of the moon, the water is drawn up first toward one end of the basin, then toward the side adjoining it, and finally (still rotating) toward the other two sides. Use a cup or other container to represent the basin; tip it slightly, and rotate it on its base. This demonstration shows that the tide in the basin does not consist of a simple rise or fall of the entire water level; rather it involves a rotation of the entire body of water in the basin.

The lines connecting the points at which the tide waters reach the same height are called the nodal or cotidal lines of the basin. Illustration 4b shows the crossing of several cotidal lines, which meet at a point called the amphidromic point.

5

TIDAL BEHAVIOR IN PART OF THE NORTH SEA—This map is designed to show the behavior of the tide in the part of the North Sea adjacent to England, France, the Netherlands, Denmark, and Norway. The lines marked on the map indicate places where the tide reaches the same height a certain number of hours following the moon's passage across the meridian. The tidal behavior obviously is complicated; this basin, limited as it is, contains as many as three amphidromic points.

facing the moon; it is least between the moon and the water particles on the side of the Earth facing away from the moon. Consequently, the water on one side of the Earth bulges toward the moon, while that on the opposite side of the Earth (the least attracted) bulges away from the moon. Now the Earth is continually rotating on its axis, and this movement relative to the moon causes the bulges of high water to move also. As a result, most ocean shores have two high tides daily.

The sun, although far larger than the moon, exerts less gravitational influence on the waters of the Earth, principally because it is located at such a great distance from this planet. Nevertheless, during the new-moon and full-moon phases, the sun, moon, and Earth are in direct line or nearly direct line; then the attraction of the sun is added to that of the moon and causes higher tides than usual.

When the gravitational pulls of the sun and moon are at right angles to each other, they tend to counterbalance each other somewhat and produce lower tides than usual. These are the so-called neap tides, which occur during the half-moon phases.

On the open sea, especially in deep water, the effects of the tides are scarcely measurable. However, at most places bordering the sea, tidal effects are quite noticeable. In most places, the interval between high tides is about 12 hours 25 minutes (about half a lunar day), but the interval varies from day to day and from place to place.

Ordinarily, along the ocean shore, the time required for the tide to rise is about equal to the time required for it to fall. In estuaries, however, the tide rises much more rapidly than it falls. The water entering an estuary possesses a certain amount of energy, which is preserved except for a tiny fraction that dissipates as the water rises in the estuary. Because the estuary becomes progressively narrower, the force exerted by the water remains constant and the height of the tidal wave continually increases. In London, for example, the tidal wave moving up the Thames may reach a height in excess of 3 m (about 10 ft). In some very narrow bays with wide openings onto the sea, the tide may rise 6 m (about 20 ft) or more. In the Bay of Fundy, it has risen as much as 15 m (about 50 ft).

ABBREVIATIONS

A	ampere
Å	Angstrom unit
abs	absolute
a-c	alternating current (as an adjective)
amu	atomic mass unit
atm	atmosphere
at. wt	atomic weight
AU	astronomical unit
avdp	avoirdupois
Bev	one billion electron volts
bhp	brake horsepower
bhp-hr	brake horsepower-hour
bp	boiling point
Btu	British thermal unit
C	temperature Celsius; temperature Centigrade
c	candle
cal	calorie
cfm	cubic feet per minute
cfs	cubic feet per second
cgs	centimeter-gram-second (system)
cl	centiliter
cm	centimeter
cm^2	square centimeter
cm^3	cubic centimeter
coef	coefficient
colog	cologarithm
cos	cosine
cot	cotangent
cp	candlepower
csc	cosecant
cu	cubic
cu ft	cubic foot
db	decibel
d-c	direct current (as an adjective)
doz	dozen
E	electromotive force
e	the base of the system of natural logarithms
ev	electron volt
F	temperature Fahrenheit
fp	freezing point
fpm	feet per minute
fps	feet per second
ft	foot; feet
ft^2	square foot
ft^3	cubic foot
ft-c	footcandle
ft-lb	foot-pound
G	universal gravitational constant
g	gram
gal	gallon
g-cal	gram-calorie
gpm	gallons per minute
gps	gallons per second
hr	hour
$h\nu$	photon energy
hp	horsepower
Hz	hertz (cycles per second)
I	electric current
ID	inside diameter
in.	inch
in.^{2}	square inch
in.^{3}	cubic inch
in.-lb	inch-pound
ips	inches per second
j	joule
K	temperature Kelvin (absolute)
kcal	kilocalorie
kg	kilogram
kg-cal	kilogram-calorie
kg-m	kilogram-meter
kg/m^3	kilograms per cubic meter
kgps	kilograms per second
km	kilometer
kv	kilovolt
kw	kilowatt
kwhr	kilowatt-hour
l	liter; lumen
lat	latitude
lb	pound
lb-ft	pound-foot
lb/ft^2	pounds per square foot
lb/ft^3	pounds per cubic foot
lb-in.	pound-inch
l-hr	lumen-hour
lin ft	linear foot
log	logarithm (common)
$\log_e$	logarithm (natural)
long.	longitude
m	meter; minute (time, in astronomical circles)
m^2	square meter
m^3	cubic meter
ma	milliampere
Mev	one million elect n volts
mg	milligram
mh	millihenry
mi	mile
mi^2	square mile
min	minute
m-kg	meter-kilogram
ml	milliliter
mm	millimeter
mm^2	square millimete
mm^3	cubic millimete
$m\mu$	millimicron
mph	miles per hour
mphps	miles per hour p cond
mv	millivolt
N	Avogadro's const
n!	factorial *n*
OD	outside diamete
oz	ounce
pH	rating on acid-alk ne scale
ppm	parts per millio
psi	pounds per squa h
psia	pounds per squa h absolute
R	temperature Re ur; resistance
RA	right ascension
rpm	revolutions per n e
rps	revolutions per
sec	secant; second
sin	sine
sp gr	specific gravity
sq	square
tan	tangent
V	volt
VA	volt-ampere
W	watt; work
yd	yard
yd^2	square yard
yd^3	cubic yard

SCIENTIFIC SYMBOLS AND ABBREVIATIONS

α	alpha particle
β; β^-	beta particle
β^+	positron
γ	gamma radiation
Δ	a small change; heat
λ	wavelength; radioactive-decay constant
ma	milliampere
μc	microcurie
μf	microfarad
μin.	microinch
μm	micron
$\mu\mu$	micromicron
$\mu\mu f$	micromicrofarad
ν	frequency; neutrino
π	3.14159; osmotic pressure
Σ	the sum of
σ	nuclear cross section (barns); area
Ω	electrical resistance (ohms)
ω	angular speed; angular velocity
$'$	minute (angular measure)
$''$	second (angular measure)
♂	male
♀	female
$>$	is greater than
$<$	is less than
$\propto$	is proportional to
∞	infinity
$\sqrt{\ }$	square root of
$^\circ$	degrees; temperature; angle measurement (example, 30°)
[ ]	molar concentration
$+$	positive electric charge; mixed with, plus
$-$	negative electric charge; single covalent bond; minus
$=$	equals; double covalent bond; produces
$\neq$	does not equal
$\equiv$	triple covalent bond
$\rightarrow$	produces; forms; chemical reaction
$\rightleftarrows$	reversible chemical reaction
$\uparrow$	gas produced by a chemical reaction
$\downarrow$	precipitate produced by a chemical reaction
$*$	radioactive substance (follows symbol of element; example, Cl^*)

THE ILLUSTRATED SCIENCE DICTIONARY

Deficiency to Double Stars

KEY TO PRONUNCIATION

The diacritical marks are:

ə	ban*a*n*a*, *a*but	e	b*e*t	th	*th*in
ᵊ	preceding l, m, n as in battl*e*	ē	b*ea*t	t̲h̲	*th*en
ė	*e*lectric	i	t*i*p	ü	r*u*le, f*oo*l
ər	f*ur*ther	ī	b*i*te	u̇	p*u*ll, w*oo*d
a	m*a*t	j	*j*ob, *g*em	ue	German h*ü*bsch
ā	d*ay*	ŋ	si*ng*	u̅e̅	French r*ue*
ä	c*o*t, f*a*ther	ō	b*o*ne	yü	*u*nion
au̇	n*ow*, *ou*t	ȯ	*saw*, *a*ll	zh	vi*s*ion
		ȯi	c*oi*n		

ˈ mark preceding the syllable with strongest stress.

ˌ mark preceding a syllable with secondary stress.

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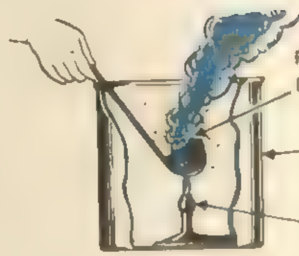
deficiency \di-'fish-ən-sē\ *n.*
BIOLOGY. A state or quality of being without something essential, such as vitamins, necessary for the well-being of an organism; also, a defect in, or lack of function of, an organ or part.

One of the problems in dieting is avoiding a vitamin or mineral DEFICIENCY.

deficiency disease \di-'fish-ən-sē diz-'ēz\
BIOLOGY. A disease, such as scurvy, rickets or pellagra, caused by a lack of certain vitamins or minerals in the diet.

Scurvy is a DEFICIENCY DISEASE *caused by a lack of vitamin C, or ascorbic acid.*



DEFLAGRATION

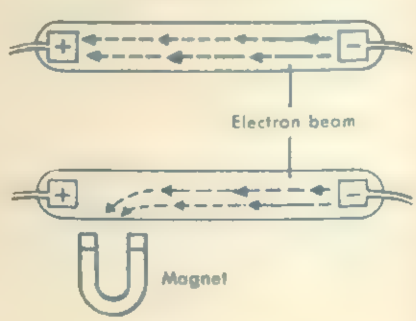
definite composition \'def-(ə-)nət ,käm-pə-'zish-ən\
CHEMISTRY. The principle that all compounds have a fixed percentage by weight of constituent elements.

The principle of DEFINITE COMPOSITION *is illustrated by the fact that water is 1/9 hydrogen and 8/9 oxygen by weight, regardless of where or how the water is formed.*

definite proportions \'def-(ə-)nət prə-'pōr-shənz\
CHEMISTRY. A principle stating that for every compound the relative numbers of atoms of its constituent elements are represented by fixed whole number ratios.

The principle of DEFINITE PROPORTIONS *makes it possible to create a chemical formula that is always true for a given substance.*

CATHODE RAY TUBE



DEFLECTION

deflagration \,def-lə-'grā-shən\ *n.*
CHEMISTRY. A vigorous chemical reaction producing heat or light or both, but not occurring so fast as to produce an explosion.

Laboratory DEFLAGRATION *of phosphorus in air should take place in a heat-resistant container located where fumes will be carried away.*

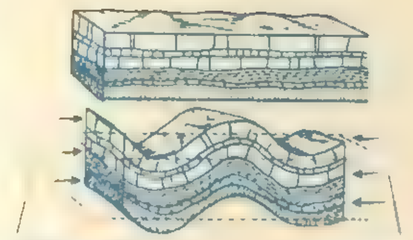
deflation \di-'flā-shən\ *n.*
1. EARTH SCIENCE. The erosive action of wind in carrying soil or rock particles from one place to another. 2. PHYSICS. The release of air or other gas from a collapsible container.

DEFLATION *is least active in areas where the soil is protected from wind by thick vegetation.*

deflection \di-'flek-shən\ *n.*
PHYSICS. A change in the path or direction of an electron beam; also, the movement of a pointer or other indicator on a scale;

also, a change in the direction of a moving mass acted on by an unbalanced force.

DEFLECTION *of an electron beam in a cathode-ray tube is caused by electric or magnetic forces.*



DEFORMATION

deflocculation \(ˌ)dē-ˌfläk-yə-ˈlā-shən\ *n.*
CHEMISTRY. The process of breaking up clumps of particles into smaller fragments of colloidal size; peptization.

Sodium silicate may be added to water to aid the the DEFLOCCULATION *of clay that is to be suspended in the water.*

deformation \ˌdē-ˌfȯr-ˈmā-shən\ *n.*
EARTH SCIENCE. Any change of volume or shape in the crust of the earth or in rock masses resulting from the forces that produce folding, faulting and plastic flow.

Tectonic, or mountain-building, forces produce DEFORMATION.

DEGENERATION

degeneration \di-ˌjen-ə-ˈrā-shən\ *n.*
1. BIOLOGY. A gradual change or regression of an organism to a lower form of development; also, the deterioration of an organ to a diminished or vestigial state in the course of the evolutionary process. 2. MEDICINE. The physical process whereby tissues totally or partially fail to replace damaged or worn-out cells; also, a gradual deterioration resulting from chemical changes within tissues.

The appendix, a small saclike appendage of the large intestine, has undergone DEGENERATION *and lost its function as a digestive organ.*

degradation \ˌdeg-rə-ˈdā-shən\ *n.*
1. EARTH SCIENCE. A wearing down or lowering of land surfaces through the processes of weathering, mass-wasting and erosion. 2. CHEMISTRY. A gradual decomposition of complex molecules into simpler molecules by a series of intermediate steps.

DEGRADATION *is continually making changes in the physical appearance of land surfaces.*


DEGRADATION

degradation of energy \ˌdeg-rə-ˈdā-shən əv ˈen-ər-jē\
PHYSICS. The natural tendency for available energy to become less available or unavailable; the second law of thermodynamics; see *entropy*.

When air is heated by a flame, DEGRADATION OF ENERGY *occurs as the difference in temperature between the hot, expanding air and surrounding cool air becomes less.*

degree \di-'grē\ *n.*
1. PHYSICS. An arbitrary unit of measurement; most frequently, the distance between marks on a scale used to measure temperature or heat intensity. 2. MATHEMATICS. A unit of measure of arcs and of angles equal to 1/360 of the circumference of a circle; also, in algebra, the sum of the exponents of the literal factors of a term, as 5 is the sum of the exponents of the literal factors of $3x^4y$.

One Centigrade DEGREE *is equal to $\frac{5}{9}$ of one Fahrenheit degree.*

DEHISCENT

dehiscent \di-'his-ᵊnt\ *adj.*
BOTANY. Referring to the bursting or opening of a pod or anther in the discharge of seeds, pollen or fruit.

Peas are the edible seeds of a DEHISCENT *plant.*

dehydration \ˌdē-ˌhī-'drā-shən\ *n.*
1. CHEMISTRY. The removal of water from a chemical compound or a mixture. 2. BIOLOGY. A reduction of the fluid in living tissues.

Sulfuric acid is used for the DEHYDRATION *of gases.*

deionization \(ˌ)dē-ˌī-ən-ə-'zā-shən\ *n.*
CHEMISTRY. The process of removing ions from a liquid or a gas; also, the recombining of positive and negative ions to form neutral atoms or molecules.

Hard water can be softened by DEIONIZATION.

deliquescence \ˌdel-i-'kwes-ᵊn(t)s\ *n.*
CHEMISTRY. The phenomenon in which a substance absorbs moisture from the atmosphere and dissolves.

Solid sodium hydroxide will show DELIQUESCENCE *better in a humid atmosphere than in dry air.*

DELTA
(MISSISSIPPI RIVER)

delta \'del-tə\ *n.*
EARTH SCIENCE. A triangular or fan-shaped land deposit at the mouth of a stream or river, roughly in the shape of the Greek letter delta (Δ).

A DELTA *results from increased sediment deposits as a stream slows down when it enters a larger body of water.*

delta wing \'del-tə 'wiŋ\
AERONAUTICS. A triangularly-shaped aircraft wing having a large sweepback angle at its leading edge, and a straight trailing edge.

A DELTA WING *allows a smoother transition from subsonic to supersonic flight than does a conventional wing.*

deltoid \'del-ˌtȯid\ *adj.*

1. ANATOMY. Referring to a muscle that covers the shoulder and helps to raise the arm away from the side of the body. 2. Referring to any object having a triangular shape or outline.

The DELTOID *muscle is one of the abductor muscles.*

DEMODULATION

demodulation \(ˌ)dē-ˌmäj-ə-'lā-shən\ *n.*

PHYSICS. The process by which information is obtained from a coded signal, also, in a radio receiver, the separation of audio frequencies from the carrier frequency.

The function of the crystal in a crystal radio receiver is to produce DEMODULATION *of the signals coming in.*

demulsifier \di-'məl-sə-ˌfī-ər\ *n.*

CHEMISTRY. A chemical that promotes separation of the components of an emulsion and that acts in an opposite manner from an emulsifier.

Dilute acid added to milk acts as a DEMULSIFIER *and causes the suspended milk solids to clump together.*

DENDRITE

denature \(')dē-'nā-chər\ *v.*

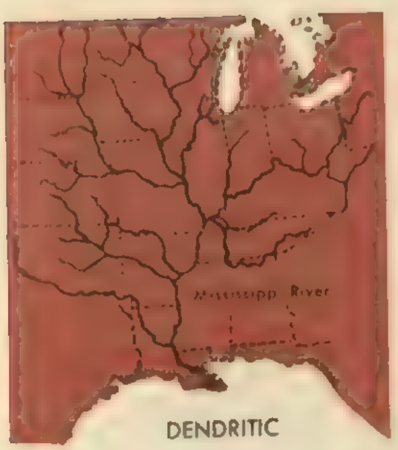
CHEMISTRY. To modify a substance so that it is unfit for human consumption, although still suitable for other purposes.

To sell ethyl alcohol for industrial purposes, without federal tax, the manufacturer must DENATURE *the product with certain poisonous chemicals.*

dendrite \'den-ˌdrīt\ *n.*

1. PHYSIOLOGY and ZOOLOGY. Any of the minute, many-branched endings of a nerve cell, or neuron, that conducts nerve impulses toward the nerve cell body, also called dendron. 2. EARTH SCIENCE. A branching pattern within or on the surface of rock or mineral masses, caused by the crystallization of another mineral substance.

A DENDRITE *leads impulses into the cell body, while another projection called the axon carries them away.*



DENDRITIC

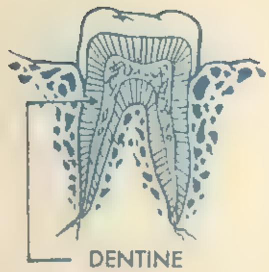
dendritic \den-'drit-ik\ *adj.*

1. EARTH SCIENCE. Referring to drainage patterns with irregular branching of tributary streams from many directions. 2. Referring to any branching pattern.

When viewed on a map or from an airplane, a DENDRITIC *drainage pattern resembles the branching of an oak or maple tree*

denitrification \(ˌ)dē-ˌnī-trə-fə-ˈkā-shən\ *n.*
BIOLOGY and EARTH SCIENCE. The removal of nitrogen compounds from the soil.

The DENITRIFICATION *of farmland can be combatted or prevented by proper crop rotation.*



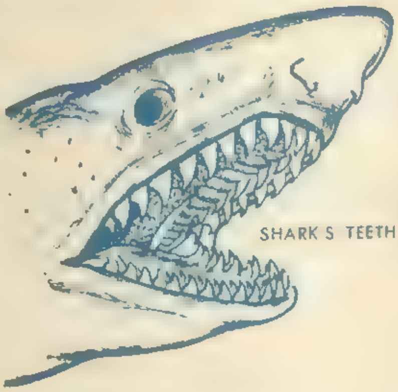
denominator \di-ˈnäm-ə-ˌnāt-ər\ *n.*
MATHEMATICS. In a fraction, the term placed below the dividing line, or fraction bar; in a common fraction, the number that tells into how many parts the whole unit is divided; in the fractional notation of division, the divisor.

The DENOMINATOR *of the fraction ¼ is 4, and the numerator is 1.*

density \ˈden(t)-sət-ē\ *n.*
1. PHYSICS. The ratio of the mass of a substance to its volume. 2. The distribution of a quantity per unit of volume or area, such as the closeness of stars in a cluster or the number of people per square mile.

The DENSITY *of iron is greater than that of wood.*

DENTITION

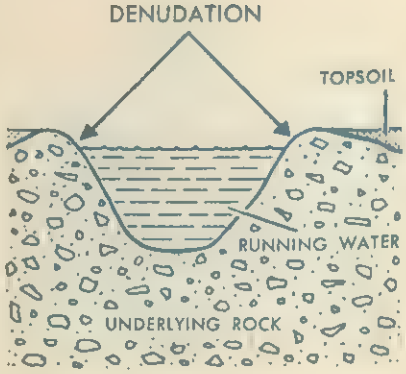


density current \ˈden(t)-sət-ē ˈkər-ənt\
EARTH SCIENCE. A current in fluids, such as in water or air, caused by differences in density within the main fluid body; a turbidity current.

The differences in density that cause a DENSITY CURRENT *are due to variations in temperature, differences in salinity or material held in suspension.*

dentine \ˈden-ˌtēn\ *n.*
1. ANATOMY. The hard, dense, calcareous tissue of the teeth that surrounds the pulp cavity and that is covered by enamel. 2. ZOOLOGY. A substance present in the toothlike scales of sharks and related fishes; also spelled dentin.

DENTINE *resembles bone in its structure but is harder and denser.*



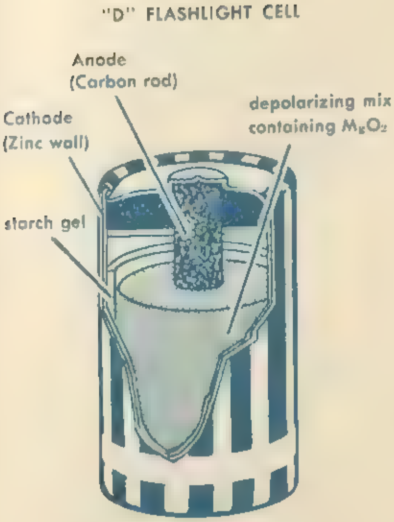
dentition \den-ˈtish-ən\ *n.*
ANATOMY and ZOOLOGY. The characteristics of a set of teeth, such as size, location, arrangement and development; also, the process of cutting teeth.

The DENTITION *of some sharks includes two rows of teeth in each jaw.*

denudation \ˌdē-(ˌ)n(y)ü-ˈdā-shən\ *n.*
EARTH SCIENCE. The washing away of covering layers of soil

or rock, exposing underlying rock formations; also, the removal or destruction of vegetation growing on land surfaces.

DENUDATION is usually a very slow process, but in the case of flash floods may be a rapid washing away of soil.



DEPOLARIZE

deoxidize \(')dē-'äk-sə-ˌdīz\ *v.*
CHEMISTRY. To remove oxygen from a compound or metal alloy.

Calcium is used to DEOXIDIZE molten steel in several industrial processes.

deoxygenation \(ˌ)dē-ˌäk-si-jə-'nā-shən\ *n.*
BIOLOGY. The removal of oxygen, particularly free oxygen, from water by fish and certain other animals.

Fish and some amphibians use gills for the DEOXYGENATION of water in their respiratory processes.

deoxyribonucleic acid \dē-ˌäk-sē-'rī-bō-n(y)ü-ˌklē-ik 'as-əd\
BIOLOGY. An acid carried by the proteins within the nucleus of living cells. It plays an important part in the transmission of hereditary characteristics; *abbr.* DNA.

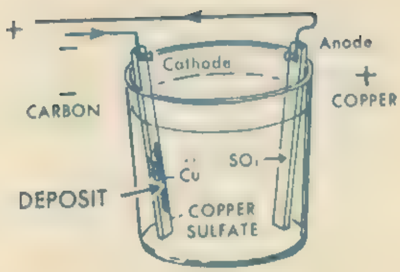
All genes contain DEOXYRIBONUCLEIC ACID.

dependent variable \di-'pen-dənt 'ver-ē-ə-bəl\
MATHEMATICS. A variable whose value depends upon, or is determined by, the value assigned to another variable called the independent variable.

In the equation $y = 2x + 2$, the value of the DEPENDENT VARIABLE y is 8 when x is assigned the value 3.

depolarize \(')dē-'pō-lə-ˌrīz\ *v.*
1. CHEMISTRY. To prevent the accumulation of waste products, usually hydrogen, that cause a reduction of voltage in an electrolytic cell. Oxides are often used for such waste prevention. 2. PHYSICS. To destroy the magnetic or electrical polarity of an object.

Since manganese dioxide acts quickly upon hydrogen, it is used to DEPOLARIZE the common flashlight cell.

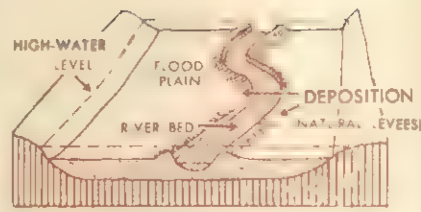


deposit \di-'päz-ət\ *n.*
1. CHEMISTRY. A metal film left on another material by electrolytic action. 2. EARTH SCIENCE. Any earth material dropped by the action of wind, water or moving ice; also, any mineral concentrated by chemical action. 3. Any material left on the surface of another material by mechanical or chemical action.

A DEPOSIT of cadmium protects metal parts from corrosion.

deposition \\,dep-ə-'zish-ən\\ *n.*
EARTH SCIENCE. The dropping of earth material from such natural carriers as floods, streams, seas, winds and glaciers; sedimentation.

The DEPOSITION *of sediment by rivers forms low, broad ridges called natural levees.*



DEPOSITION

depression \\di-'presh-ən\\ *n.*
1. EARTH SCIENCE. A low place on the surface of the earth, generally surrounded on all sides by higher ground; also, an area of low atmospheric pressure relative to surrounding areas. 2. ASTRONOMY. The angular distance of a celestial object below the horizon, expressed in degrees; negative altitude. 3. PHYSICS. A lowering of the freezing point of a pure liquid, caused by the presence of one or more substances in solution.

One theory of the formation of the Great Lakes is that each is a DEPRESSION *formed by glaciation.*

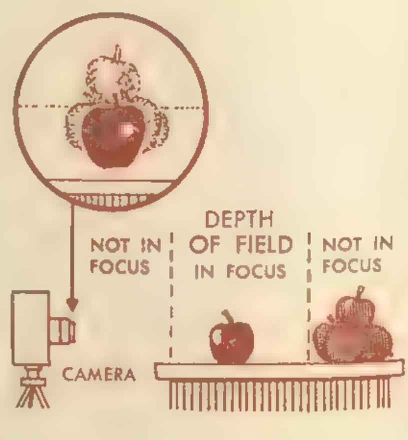
DEPRESSION (GREAT LAKES AREA)

depressor \\di-'pres-ər\\ *n.*
1. PHYSIOLOGY. A nerve that, when stimulated, slows down or stops the processes of the part or area it controls. 2. ANATOMY. Any muscle that lowers or draws down an external part of the body. 3. MEDICINE. A chemical that slows down or stops certain body processes; also, a device that restrains or holds the tongue during medical treatment or examination.

Stimulation of the aortic DEPRESSOR *always causes blood pressure to fall.*

depth of field \\'depth əv 'fēld\\
PHYSICS. The range of distances to an object that will produce a satisfactorily-sharp image through a lens in an optical instrument, such as a telescope or camera.

Decreasing the effective diameter of a lens by narrowing a diaphragm opening increases the DEPTH OF FIELD *of the lens.*



derivative \\di-'riv-ət-iv\\ *n.*
1. CHEMISTRY. A material derived from another material or so related by structure that it appears to be derived from another material. 2. MATHEMATICS. In calculus, the limit of the ratio of the change in the value of the dependent variable to the change in the value of the independent variable as the latter change approaches zero as a limit; the instantaneous or immediate rate at which one variable changes with respect to changes in the value of another variable; a derived function.

Methanol is a DERIVATIVE *of methane.*

derived quantity \di-'rīvd 'kwän(t)-ət-ē\

MATHEMATICS. A value which is estimated from experimental measurements.

The accuracy of a DERIVED QUANTITY *is influenced by the exactness of the experimental measurements preceding it.*

derived unit \di-'rīvd 'yü-nət\

MATHEMATICS. A unit of measurement based on a combination of two or three of the fundamental units: mass, length and time.

Velocity, or length traveled per unit time, is a DERIVED UNIT.


DERMATOID

dermatoid \'dər-mə-ˌtȯid\ *adj.*

ANATOMY and ZOOLOGY. Referring to the skin or to that which resembles skin; skinlike.

Some DERMATOID *diseases may be successfully treated with ultraviolet radiation.*

dermis \'dər-məs\ *n.*

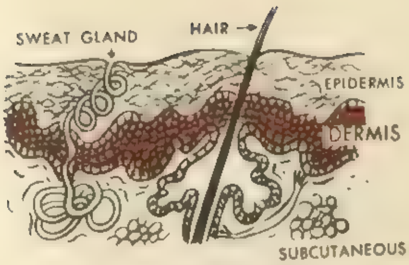
ANATOMY and ZOOLOGY. The layer of skin just beneath the epidermis; the true skin.

The DERMIS *contains elastic fibrous tissue, many blood and lymph vessels, nerves, smooth-muscle fibers, hair follicles, glands and fat deposits.*

desalinization \(')dē-ˌsā-ˌlēn-ə-'zā-shən\ *n.*

CHEMISTRY. A method by which salt is removed from soil, water or some other substance.

The membrane process of DESALINIZATION *makes ocean water safe to drink.*



DERMIS

descendant \di-'sen-dənt\ *n.*

BIOLOGY. Any offspring, regardless of how many generations there are between it and a given ancestor.

The modern bird is a DESCENDANT *of a prehistoric reptile.*

desensitize \(')dē-'sen(t)-sə-ˌtīz\ *v.*

1. MEDICINE. To deprive an area of the body of sensation; also, to paralyze a sensory nerve by cutting it or by applying a drug; also, to prevent allergic reactions by removing the antibodies from a sensitized cell. 2. CHEMISTRY. To change the condition of a substance so that a given reaction can no longer occur, as in chemical processes affecting light-sensitive materials used in photography.

In dental surgery, the local anesthetic novocaine is often used to DESENSITIZE *the nerves of the jaw.*

desert \'dez-ərt\ *n.*
EARTH SCIENCE. A large, almost barren area that may be either hot with scanty rainfall, as the Gobi Desert in Asia, or very cold, as Antarctica; generally, an area with scanty, irregular rainfall and sparse vegetation.

Plant and animal life in a DESERT *is limited by the extremes of temperature and the restricted water supply.*

desiccate \'des-i-ˌkāt\ *v.*
To dry; to remove moisture.

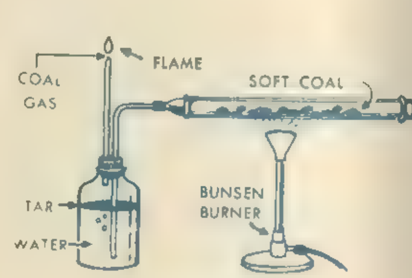
Dehumidifiers partially DESICCATE *the air in a room.*

desmid \'dez-məd\ *n.*
BIOLOGY. Any of a genus of bright-green freshwater algae, similar to diatoms except for the cell wall, and composed of cellulose rather than silica.

A DESMID *is a unicellular organism.*

desmoid \'dez-ṁoid\ *adj.*
ANATOMY. Referring to tissue that is dense and fibrous, as in a ligament.

Some tumors are composed mainly of fully-developed DESMOID *tissue.*



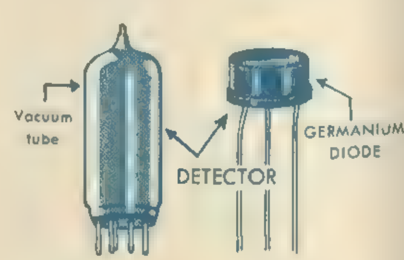
DESTRUCTIVE
DISTILLATION

destructive distillation \di-'strək-tiv ˌdis-tə-'lā-shən\
CHEMISTRY. The process of heating a substance in the absence of air to bring about partial decomposition. At least one of the products of decomposition is a vapor, and all products of decomposition are simpler than the original substance.

Coal tar and coke are products of the DESTRUCTIVE DISTILLATION *of coal.*

destructive metabolism \di-'strək-tiv mə-'tab-ə-ˌliz-əm\
BIOLOGY and PHYSIOLOGY. The processes in plants and animals by which complex body tissues are broken into simpler substances; also called catabolism.

DESTRUCTIVE METABOLISM *is accompanied by a release of energy.*



detector \di-'tek-tər\ *n.*
PHYSICS. The part of a radio circuit that recovers the original signal from a radio carrier wave.

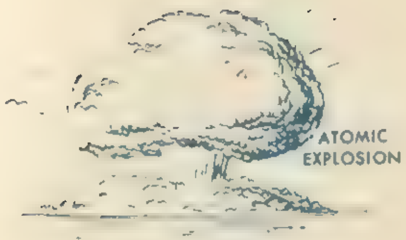
The vacuum tube has replaced the crystal as the DETECTOR *in all but the simplest radios.*

deterge \di-'tərj\ *v.*
MEDICINE. To clean away or out; to cleanse.

It is necessary to DETERGE *a wound in which there is dirt or foreign material.*

detergents \di-'tər-jənts\ *n.*
CHEMISTRY. Cleansing substances that act by emulsion to lower the surface tension of water. Detergents are divided into two main types: soaps and synthetic detergents.

Synthetic DETERGENTS *do not produce a surface scum when used with hard water.*



DETONATION

determinant \di-'tərm-(ə-)nənt\ *n.*
MATHEMATICS. A square array of numbers, or elements, aligned in rows and columns, indicating the sum of specific products of these elements.

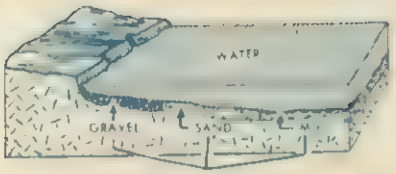
The third-order DETERMINANT
$$\begin{matrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{matrix}$$
equals $a_1b_2c_3 + a_2b_3c_1 + a_3b_1c_2 - a_3b_2c_1 - a_1b_3c_2 - a_2b_1c_3$.

detonation \ˌdet-ᵊn-'ā-shən\ *n.*
1. PHYSICS. An explosion. 2. ENGINEERING. In an engine, an excessively-rapid combustion that replaces or accompanies normal combustion and that can be recognized by overheating, reduced power and knocking.

The DETONATION *of a nuclear bomb for testing must occur under carefully-controlled conditions.*

detonator \'det-ᵊn-ˌāt-ər\ *n.*
PHYSICS. An easily-exploded charge, or a device containing it, used to set off a high explosive.

Fulminate of mercury is often used in a blasting cap as a DETONATOR *for dynamite.*



DETRITUS

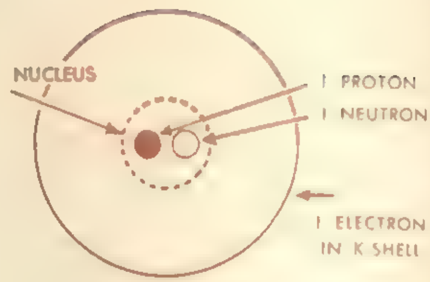
detritus \di-'trīt-əs\ *n.*
EARTH SCIENCE. Any loose material that results from the weathering or disintegration of rock; also, a deposit of rock fragments.

Examples of DETRITUS *are such materials as gravel, sand, silt and clay.*

deuterium \d(y)ü-'tir-ē-əm\ *n.*
CHEMISTRY and PHYSICS. An isotope of hydrogen, differing from the ordinary hydrogen atom in that its nucleus contains a

neutron. Its atomic mass is approximately twice that of ordinary hydrogen. Symbol, D; also known as heavy hydrogen.

It has been found that approximately 0.02 percent of ordinary hydrogen is DEUTERIUM.



DEUTERIUM
(ATOM)

deuteron \'d(y)üt-ə-ˌrän\ *n.*
CHEMISTRY and PHYSICS. The nucleus of a deuterium atom.

A DEUTERON *having a high level of energy may penetrate the nucleus of a target atom and cause a nuclear reaction.*

developer \di-'vel-ə-pər\ *n.*
CHEMISTRY. A chemical solution used to develop films by reducing the exposed silver salts on the film to metallic silver; also, a reagent used in dyeing fiber.

The temperature of a DEVELOPER *influences its rate of reaction and must be carefully controlled.*

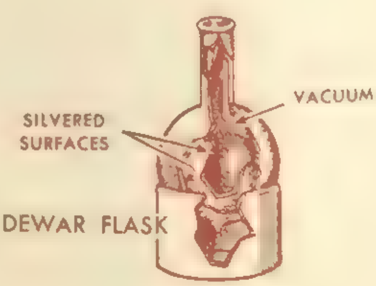
deviation \ˌdē-vē-'ā-shən\ *n.*
1. MATHEMATICS. In a set of numbers, the difference between one particular number and the average, or mean, of the set; also, a change from a trend. 2. PHYSICS. The changing of a light ray from its original path, measured by the angle between the original ray and the bent ray; also, the veering of a free-falling body from a straight line because of the rotation of the earth. 3. AERONAUTICS and EARTH SCIENCE. The deflection of a compass needle from magnetic north due to local magnetic conditions or ferrous metals near the compass; also, the attraction or repulsion of a compass needle by metal parts, electrical equipment or tools; not to be confused with magnetic declination or variation. 4. BIOLOGY. An abnormal variation from the usual growth or development of a body part.

The DEVIATION *of a number from an average is considered positive if it is greater than the average and negative if it is less.*

DEW

dew \'d(y)ü\ *n.*
EARTH SCIENCE. Small drops of water that form on grass, leaves and other surfaces that are cooler than the surrounding air; in effect, the condensation of water vapor in the air when it comes in contact with any surface cold enough to cool the air below the dew point.

The water drops that form on the outside of a glass of ice water are a form of DEW.



DEWAR FLASK

Dewar flask \'d(y)ü-ər 'flask\
CHEMISTRY and PHYSICS. A glass or metal vessel for liquid air,

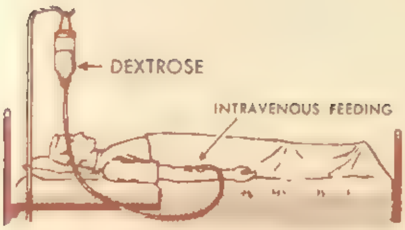
constructed with a vacuum between two walls to prevent conduction and convection of heat.

The DEWAR FLASK *keeps air in liquid form in the same manner that a thermos bottle keeps liquids hot or cold.*

dew point \'d(y)ü 'point\

EARTH SCIENCE. The temperature at which the atmosphere becomes saturated with water vapor.

Cooling of an air mass below the DEW POINT *results in condensation of the water vapor to form clouds, dew, frost or fog.*



DEXTROSE

dextrin \'dek-strən\ *n.*

CHEMISTRY. $(C_6H_{10}O_5)_x$. A soluble carbohydrate solid, white or yellow in color, formed when starch is heated gently or treated with dilute acids.

DEXTRIN *is classified as a polysaccharide, one of the three main categories of carbohydrates.*

dextrose \'dek-ˌstrōs\ *n.*

CHEMISTRY. $C_6H_{12}O_6$. A simple sugar, or monosaccharide, obtained commercially by the hydrolysis of cornstarch. The most abundant sugar in nature, it is also called glucose, corn sugar, or grape sugar.

DEXTROSE *is often used for intravenous feeding.*

diadromous \dī-'ad-rə-məs\ *adj.*

ZOOLOGY. Referring to an organism that migrates periodically between salt and fresh water.

The salmon's DIADROMOUS *nature has increased its popularity as a sport fish.*

DIAGEOTROPISM

diagenesis \ˌdī-ə-'jen-ə-səs\ *n.*

EARTH SCIENCE. The changes that take place in rock sediments while and after they accumulate but before they consolidate into rock. The changes are caused by the weight of layers of earth and stone, by water, by chemicals or by bacteria.

DIAGENESIS *occurs in sediments deposited on the ocean bottom.*

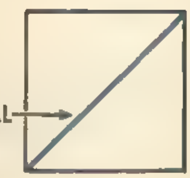
diageotropism \ˌdī-ə-jē-'ä-trə-ˌpiz-əm\ *n.*

BOTANY. The tendency of roots and branches of trees and plants to grow at right angles to the force of gravity.

The extension of roots over large horizontal areas, resulting in firm support and anchorage for trees and other plants, is a result of DIAGEOTROPISM.

diagonal \dī-'ag-ən-ᵊl\ *n.*
MATHEMATICS. A straight line drawn from one vertex to any nonconsecutive vertex of a polygon or of a polyhedron.

A DIAGONAL *of a parallelogram divides the parallelogram into two congruent triangles.*



dialysis \dī-'al-ə-səs\ *n.*
CHEMISTRY and PHYSICS. The process of separating compounds in solution by the differences in their rates of diffusion through a membrane.

Salt and protein in solution can be separated by DIALYSIS, *since salt ions diffuse through a membrane more quickly than protein molecules.*

diamagnetism \,dī-ə-'mag-nə-,tiz-əm\ *n.*
PHYSICS. The property of a substance that causes it to be weakly repelled by all magnetic fields.

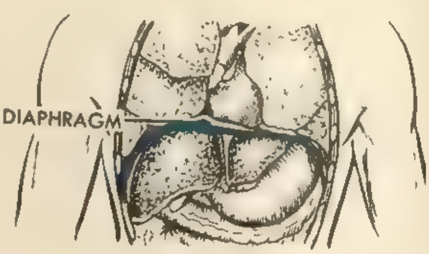
Bismuth has the greatest DIAMAGNETISM *of all the elements.*

diameter \dī-'am-ət-ər\ *n.*
MATHEMATICS. A chord of a conic section or of a central quadric surface passing through its center.

A DIAMETER *of a circle divides the circle into two semicircles.*

diamond \'dī-(ə-)mənd\ *n.*
EARTH SCIENCE. A mineral form of pure carbon and the hardest natural substance known. It occurs as individual crystals or crystalline masses.

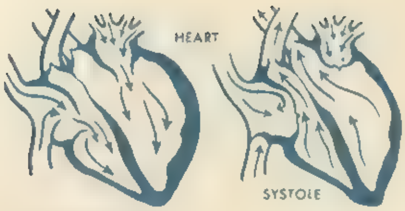
Because of its great hardness, a DIAMOND *is often used in a cutting tool or drill.*



DIAPHRAGM

diaphragm \'dī-ə-,fram\ *n.*
1. ANATOMY. The muscular tissue that separates the abdominal cavity from the chest cavity. 2. ZOOLOGY. Any thin membrane separating parts of the body cavity of an animal. 3. PHYSICS. Any plate, disk or similar object that separates two parts of a cavity; in optics, a disk with a fixed or adjustable opening to regulate the amount of light beamed toward a lens; in acoustics, a plate that vibrates in response to sound waves.

Rhythmic contraction and relaxation of the human DIAPHRAGM *occur in breathing.*



DIASTOLE

diastase \'dī-ə-ˌstās\ *n.*
BIOLOGY and CHEMISTRY. A complex chemical enzyme that aids in the conversion of starch into simpler sugar molecules.

DIASTASE is produced when barley germinates during the malting process.

diastole \dī-'as-tə-(ˌ)lē\ *n.*
PHYSIOLOGY. The expansion phase of the heartbeat during which the ventricles become filled with blood.

During DIASTOLE, the muscles of the heart are relaxed.

diastolic blood pressure \ˌdī-ə-'stäl-ik 'bləd 'presh-ər\
PHYSIOLOGY. The amount of force per unit area exerted by the blood upon the walls of the arteries when the ventricles of the heart are relaxed. The pressure is indirectly measured in millimeters of mercury by means of a pressure cuff and gauge.

In young adults, DIASTOLIC BLOOD PRESSURE may normally range from 70 to 90 mm. of mercury.

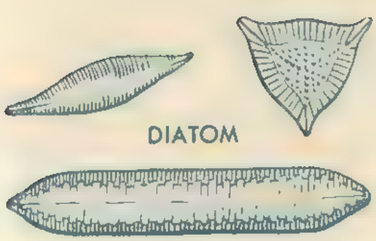
DIASTROPHISM


diastrophism \dī-'as-trə-ˌfiz-əm\ *n.*
EARTH SCIENCE. The geological processes that produce movement of a part of the earth's crust; also, a structure that results from the processes producing movement, such as a fault, a mountain or a continent.

DIASTROPHISM has been active along the borders of the Pacific Ocean in a region called the Ring of Fire.

diathermy \'dī-ə-ˌthər-mē\ *n.*
MEDICINE. The generation of body heat caused by passing high-frequency electric current through the body tissues.

Shortwave DIATHERMY produces heating of tissues by means of an oscillating current having frequencies ranging from 10 million to 100 million cycles per second.


DIATOM

diatom \'dī-ə-ˌtäm\
BOTANY. One of a species of microscopic, one-celled algae having a cell wall in two sections, or halves, one fitting over the other like a box lid. The cell wall contains small amounts of silicon and manganese.

A DIATOM may be green, but more often it is golden-brown in color.

diatomaceous earth \\,dī-ət-ə-'mā-shəs 'ərth\\
EARTH SCIENCE. A porous, light-colored, earthy material composed of diatom shells of nearly-pure silica; diatomite.

DIATOMACEOUS EARTH *is used in some scouring powders because of its mildly-abrasive properties.*

diatomic \\,dī-ə-'täm-ik\\ *adj.*
CHEMISTRY. Referring to molecules composed of two atoms.

Hydrogen, H_2, is a DIATOMIC *element*

diazo compounds \\dī-'az-(,)ō 'käm-,paúndz\\
CHEMISTRY. Carbon compounds having two nitrogen atoms linking two radicals or a radical and an atom.

In their solid state, DIAZO COMPOUNDS *may be very explosive.*

dibasic \\(')dī-'bā-sik\\ *adj.*
CHEMISTRY. Referring to a molecule containing two replaceable hydrogen atoms.

Sulfuric acid, H_2SO_4, is a DIBASIC *compound.*

dichotomous \\dī-'kät-ə-məs\\ *adj.*
Divided into two parts or branches, forked or having a dual arrangement.

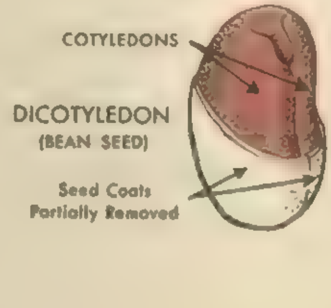
The largest artery in the body, the aorta, has a DICHOTOMOUS *structure as it divides into the two arteries that supply the legs with blood.*

dichromatic \\,dī-krō-'mat-ik\\ *adj.*
ZOOLOGY. Referring to two varieties of coloration occurring in a single kind of organism, as in certain birds and insects. This kind of coloration is independent of age or sex.

DICHROMATIC *coloration may appear in screech owls as reddish-brown streaked with black or gray streaked with black.*

dicotyledon \\,dī-,kät-ᵊl-'ēd-ᵊn\\ *n.*
BOTANY. A plant that produces two seed leaves, such as most shrubs and deciduous trees.

A DICOTYLEDON *possesses flower parts in fours or fives or in multiples of four or five.*



dielectric \\,dī-ə-'lek-trik\\ *n.*
PHYSICS. A substance that is a nonconductor of electricity; an insulator.

Plastic is now often used in place of rubber as a DIELECTRIC.

diencephalon \ˌdī-ˌen-ˈsef-ə-ˌlän\ *n.*

ANATOMY and PHYSIOLOGY. The interbrain, a centrally-located segment of the brain that includes the thalamus and hypothalamus; the posterior portion of the forebrain.

Relay stations of the nerve pathways leading from the eyes to the cerebrum are located in the DIENCEPHALON.


DIESEL ENGINE

diesel engine \ˈdē-zəl ˈen-jən\

ENGINEERING. An internal combustion engine drawing its power from the explosion of an air-oil vapor mixture. Combustion in it is caused by heat resulting from air that is compressed by a piston within a cylinder.

One of the main advantages of the DIESEL ENGINE *is low fuel cost.*

difference \ˈdif-ərn(t)s\ *n.*

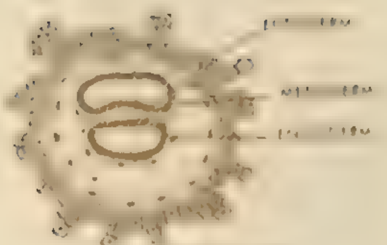
MATHEMATICS. The number obtained by subtracting one number or quantity from another; the remainder.

When 23 is subtracted from 24, the DIFFERENCE *is 1.*

differential \ˌdif-ə-ˈren-chəl\ *n.*

1 MATHEMATICS. In elementary calculus, an increment (increase or decrease) in the value of a dependent variable y, denoted by dy, that results from an arbitrary increment in the independent variable x, denoted by dx, the relationship being defined by the equation $dy = D_x y \cdot dx$ where $D_x y$ is the derivative of y with respect to x. 2 ENGINEERING. An arrangement of gears on a driving axle, as in an automobile, that permits the two halves of the axle to rotate at different speeds.

If $y = 3x^2$, then the DIFFERENTIAL *$dy = 6x \cdot dx$.*


DIFFERENTIATE

differential weathering \ˌdif-ə-ˈren-chəl ˈweth-(ə-)riŋ\

EARTH SCIENCE. Uneven weathering or wearing away of different sections of a rock mass.

DIFFERENTIAL WEATHERING *usually results from variations in the composition of a rock, but may also result from differences in amounts of weathering from one area to another on a rock surface.*

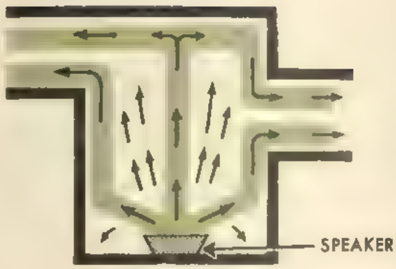
differentiate \ˌdif-ə-ˈren-chē-ˌāt\ *v.*

BIOLOGY. To become modified, as cells or tissues, also to perform different or special functions.

Early in the development of a fertilized egg, multiplying cells begin to DIFFERENTIATE *into ectoderm, mesoderm and endoderm that produce specialized tissues, organs and systems.*

diffluent \'di-ˌflü-ənt\ *adj.*
CHEMISTRY. Tending to become fluid readily; dissolving easily.

Most gelatins become DIFFLUENT *at warm temperatures.*



DIFFRACTION

diffraction \dif-'rak-shən\ *n.*
PHYSICS. The action of sound and light or other electromagnetic radiation as it passes the edge of an obstacle and spreads sideways. The action is observed only in energy forms that have wave characteristics.

DIFFRACTION *accounts in part for the ability of sound to carry around corners.*

diffraction grating \dif-'rak-shən 'grāt-iŋ\
PHYSICS. An optical device separating light into one or more spectra. The spectra are formed by the phenomenon of light interference caused by reflection from, or transmission through, closely-placed lines or scratches on a glass or metal surface. The lines may be several thousand per inch.

It is impossible to tell whether a spectrum was formed by a DIFFRACTION GRATING *or a prism simply by looking at it.*

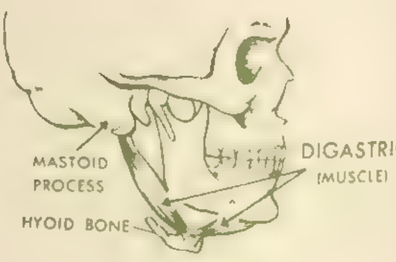

DIFFUSE NEBULA

diffuse nebula \dif-'yüs 'neb-yə-lə\
ASTRONOMY. Any one of the vast celestial structures lacking a defined shape and made up of gases or finely-divided particles. It may be either a dark or a bright structure.

The Great Nebula of Orion is a DIFFUSE NEBULA *visible through binoculars.*

diffusion \dif-'yü-zhən\ *n.*
PHYSICS. The mixing of molecules, ions or atoms as a result of their motion. The mixing proceeds more slowly at low temperatures, since the particles move less rapidly and have less kinetic energy. The process is called osmosis when it occurs through a membrane.

Gases undergo DIFFUSION *more rapidly than liquids or solids.*



DIGASTRIC (MUSCLE)

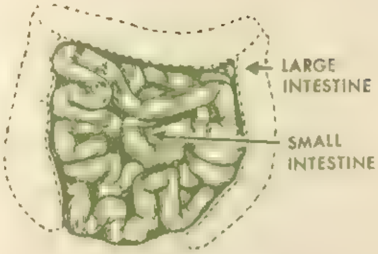
digastric \dī-'gas-trik\ *adj.*
ANATOMY. Referring to a muscle that has a fleshy part at each end and a tendon in the middle.

A DIGASTRIC *muscle depresses the lower jaw and indirectly aids in moving the tongue.*

digest \dī-'jest\ *v.*
1. PHYSIOLOGY and ZOOLOGY. To change food by breaking it down through mechanical and chemical action into simpler

compounds that can be absorbed by the tissues. 2. CHEMISTRY. To soften or convert a substance into a soluble form by heat, chemicals, pressure or some combination of these.

Ptyalin, an enzyme found in saliva, helps to DIGEST *starch and change it to sugar.*



DIGESTIVE ORGAN

digestive enzymes \dī-'jes-tiv 'en-ˌzīmz\
PHYSIOLOGY. Complex chemical substances that are produced by the cells of an organism and that act as organic catalysts in the process of breaking down food molecules.

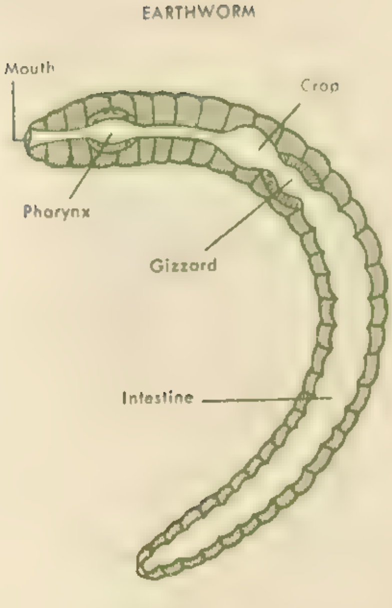
Some DIGESTIVE ENZYMES *are produced by such special glands as the salivary glands and the pancreas.*

digestive fluid \dī-'jes-tiv 'flü-əd\
PHYSIOLOGY. Any one of the secretions produced by the cells of the digestive system and used to soften foods or lubricate their passage through the digestive tract.

Bile from the gall bladder is a DIGESTIVE FLUID *that acts to emulsify fats.*

digestive organ \dī-'jes-tiv 'ȯr-gən\
ANATOMY and ZOOLOGY. In multicellular animals, any structure that functions in the processes of preparing food materials for absorption.

The small intestine of man is the DIGESTIVE ORGAN *in which much of the absorption of food takes place.*



DIGESTIVE SYSTEM

digestive system \dī-'jes-tiv 'sis-təm\
PHYSIOLOGY. All the parts of a multicellular organism that are directly involved in the processes of preparing food for absorption; also, all the organs that together function to bring about digestion.

The human DIGESTIVE SYSTEM *includes the alimentary canal, through which food passes during digestion, and a number of glands that secrete the digestive fluids.*

digit \'dij-ət\ *n.*
1. MATHEMATICS. Any of the ten symbols 1, 2, 3, 4, 5, 6, 7, 8, 9 or 0 used in writing numerals. 2. ZOOLOGY. In most vertebrates, the terminal portion of each limb. 3. ANATOMY. In man, a finger or a toe.

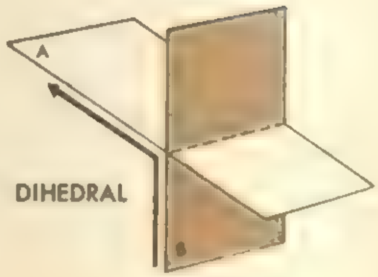
The second DIGIT *in the number 234 is 3.*

digital computer \'dij-ət-ᵊl kəm-'pyüt-ər\
MATHEMATICS. An instrument that solves mathematical problems by performing numerical calculations either mechanically or electronically.

A highly-efficient DIGITAL COMPUTER *uses transistors or vacuum tubes, which can perform hundreds of calculations per second.*

digitalis \ˌdij-ə-'tal-əs\ *n.*
MEDICINE. A drug obtained from the foxglove plant and used as a powerful heart stimulant.

DIGITALIS *causes an increase in blood pressure by increasing the strength of the heartbeat and by contracting the arterioles*



DIHEDRAL

THE PLANES AB
FORM A DIHEDRAL ANGLE

dihedral \dī-'hē-drəl\
1. MATHEMATICS. (Adj.). Having two plane faces that intersect in a straight line. 2. AERONAUTICS. (N.). The angle aircraft wings or stabilizers make with a horizontal line.

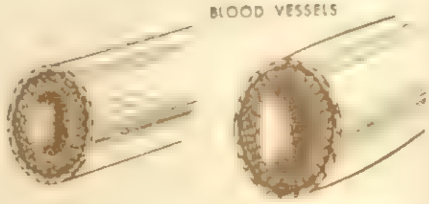
A DIHEDRAL *angle is equal in degrees to its plane angle.*

dihybrid \(')dī-'hī-brəd\ *n.*
BIOLOGY. The first generation offspring of parents differing in two heritable, or unit, characters, such as eye pigmentation or skin coloring.

A guinea pig that is a DIHYBRID *with respect to hair length and color will have black, short hair, since black and short hair are dominant over white and long hair.*

dilation \dī-'lā-shən\ *n.*
PHYSIOLOGY. The expansion of a part of the body, such as an organ or duct, beyond its normal size; also called dilatation.

During prolonged exercise, there is a DILATION *of the blood vessels in the muscles being used.*



DILATION

diluent \'dil-yə-wənt\ *n.*
CHEMISTRY. A substance that decreases the concentration of a solution or suspension when added to it.

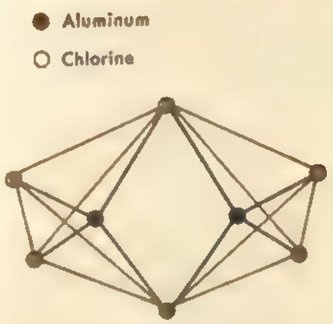
Turpentine acts as a DILUENT *when added to oil-base paints.*

dilute \dī-'lüt\
CHEMISTRY. (Adj.). Referring to a solution of relatively-low solute concentration. (V.). To reduce the concentration of dissolved matter in solution by the addition of more solvent.

Vinegar is a DILUTE *solution of acetic acid in water.*

dimer \\'dī-mər\\ *n.*
CHEMISTRY. Two identical molecules bonded in a single, larger molecule.

A disaccharide, composed of two glucose molecules, is known as a DIMER.



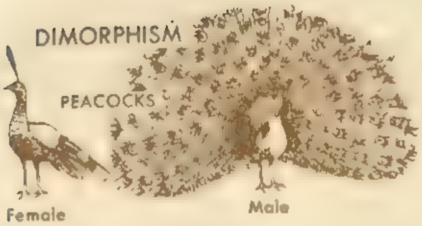
(ALUMINUM CHLORIDE)
DIMER

dimerous \\'dim-ə-rəs\\ *adj.*
BIOLOGY. Referring to something that has or is composed of two parts.

Some flowers are characterized by DIMEROUS *whorls.*

dimorphism \\dī-'mȯr-ˌfiz-əm\\ *n.*
1. ZOOLOGY. The presence of two different characteristics, such as color or size, within the same species. 2. BOTANY. The possession of two different kinds of pistils, stamens, leaves or flowers on the same plant or in the same species. 3. EARTH SCIENCE. The occurrence of two distinct forms of the same mineral.

The cardinal is one of many birds that show DIMORPHISM *in color, since the male is bright red and the female olive-brown.*



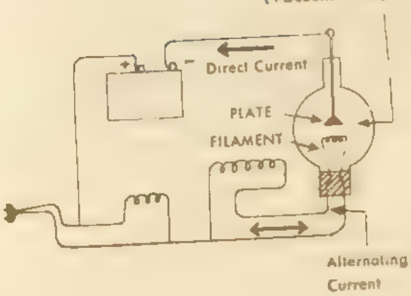
diode \\'dī-ˌōd\\ *n.*
PHYSICS. Any device that contains two electrodes and that carries electricity more readily in one direction than the other; a vacuum tube containing one anode and one cathode; a crystal or solid-state device composed of such materials as germanium or silicon; see *transistor*.

A DIODE *may be used to change an alternating current into a pulsed direct current.*

dioecious \\(')dī-'ē-shəs\\ *adj.*
1. BOTANY. Referring to plant types whose members bear imperfect flowers so that staminate flowers appear on one plant and pistillate flowers on another plant, as the willow or the cottonwood. 2. ZOOLOGY. Referring to a species whose members are divided into two sexes, male and female.

A DIOECIOUS *plant with flowers having only stamens does not bear seeds or fruit.*

DIODE
(Vacuum Tube)

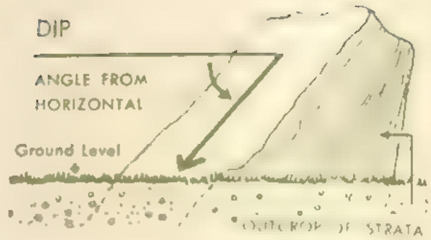


diopter \\dī-'äp-tər\\ *n.*
MEDICINE and PHYSICS. A unit used in measuring the refraction of a lens or prism. In a lens, it is the reciprocal of the focal length expressed as meters. In a prism, it is the refractive power necessary to refract light one centimeter at a distance of one meter from the prism.

A DIOPTER *is the refracting unit used in designing lenses for spectacles.*

dioptrics \dī-'äp-triks\ *n.*
PHYSICS. That branch of optics dealing with the changing of light direction by lenses; see *refraction.*

An optician uses the principles of DIOPTRICS *in making lenses for spectacles.*

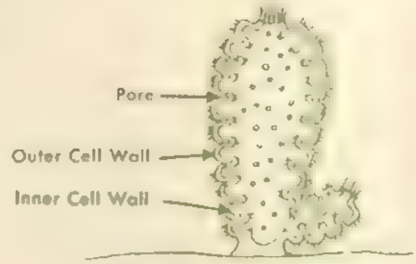


dip \'dip\ *n.*
EARTH SCIENCE. The angle or slope, of a layer of rock or other plane surface as measured from the horizontal; also, the angle between the horizontal and the position of a dipping needle representing the resultant of the horizontal and vertical components of the earth's magnetic field; also called magnetic inclination.

The DIP *of rock strata is evidence that tilting or folding has taken place, since the strata were horizontal when deposited.*

diploblastic \ˌdip-lō-'blas-tik\ *adj.*
ZOOLOGY. Referring to any multicellular animal whose body consists essentially of two basic tissue layers: an outer ectoderm and an inner endoderm.

Because ctenophores, sponges and coelenterates are DIPLOBLASTIC, *they may be historically more closely related to one another than to other animal groups.*



DIPLOBLASTIC

SIMPLE SPONGE (LONGITUDINAL SECTION)

diploid number \'dip-ˌlȯid 'nəm-ˌbər\
BIOLOGY. The complete set of chromosomes in a body cell nucleus. The set is double the number of chromosomes in a germ cell nucleus; see *haploid.*

The DIPLOID NUMBER *is usually constant for each body cell of each member of the species.*

dip needle \'dip 'nēd-ᵊl\
PHYSICS. A magnetic needle that turns freely on a horizontal axis and indicates the vertical component of the earth's magnetic field; also called an inclinometer.

At the magnetic poles of the earth, a DIP NEEDLE *will point straight up and down.*

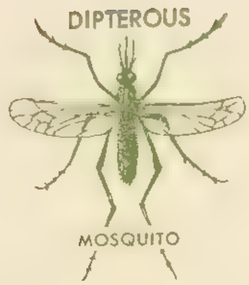
dipole \'dī-ˌpōl\ *n.*
1. PHYSICS. Two opposite electric charges or magnetic poles separated by a small distance. 2. CHEMISTRY. A molecule charged positively at one end and negatively at the other.

A bar magnet is a DIPOLE.

dipterous \'dip-tə-rəs\ *adj.*
1. ZOOLOGY. Describing insects that have two wings or that

have one pair of wings rather than two pairs, the second pair being underdeveloped and knoblike and serving only as balances. 2. BOTANY. Having two winglike appendages, as some seed pods, seeds, leaves or petals.

The housefly, the gnat and the mosquito are DIPTEROUS *insects.*



direct current \də-'rekt 'kər-ənt\
PHYSICS. A flow of electrons in only one direction, as opposed to alternating current; *abbr.* DC.

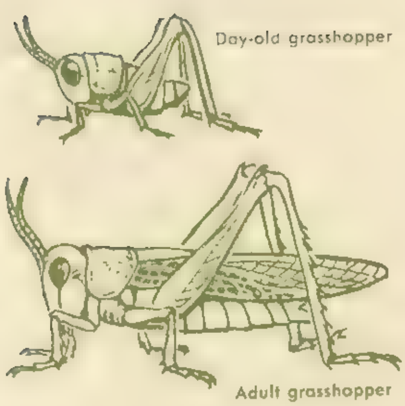
Automobile batteries provide DIRECT CURRENT.

direct metamorphosis \də-'rekt ˌmet-ə-'mȯr-fə-səs\
ZOOLOGY. In insects, the gradual development of the young, or nymphs, hatched from eggs but similar in appearance to the parents, into mature adults. It differs from metamorphosis in which the young change form completely before becoming adult, as does the frog or the butterfly.

Because grasshoppers develop by DIRECT METAMORPHOSIS, *the newly-hatched young closely resemble their parents.*

direct proportion \də-'rekt prə-'pōr-shən\
A relationship between two variable quantities whose ratio is constant. When one variable increases, the other variable increases, and when one variable decreases, the other variable decreases.

The relationship between the varying temperature and the varying pressure of a gas is a DIRECT PROPORTION *if the volume of the gas remains constant.*



DIRECT METAMORPHOSIS

directrix \də-'rek-triks\ *n.*
MATHEMATICS. In geometry, a fixed line perpendicular to a second line, or axis, and a certain distance from a fixed point called a focus, used in defining a conic, such as a parabola, hyperbola or ellipse; also, a curve or broken line in a plane through which a line generating conical, cylindrical, pyramidal and prismatic surfaces always passes.

A mechanical engineer who designs the nose cone for a guided missile starts his drawing with a DIRECTRIX.

disaccharide \(')dī-'sak-ə-ˌrīd\ *n.*
CHEMISTRY. A sugar having the general formula $C_{12}H_{22}O_{11}$. Each molecule is composed of two molecules of a simple sugar, $C_6H_{12}O_6$, one molecule of water having split off as the two molecules joined.

While cane sugar, or sucrose, is a well-known DISACCHARIDE, *milk sugar and maltose are also disaccharides.*

disc \'disk\ *n.*
Another spelling of disk. See *disk.*

discharge \dis(h)-'chärj\ *n.*
1. PHYSICS. An action by which potential electrical or hydraulic energy is changed into another form; also, the passage of an electrical current from a storage battery or dry cell; also, the passage of electrons through a gas; also, a rapid release of accumulated energy. 2. EARTH SCIENCE. The rate of fluid flow from a spring, stream, geyser or well. The flow is usually measured in volume per unit time. 3. MEDICINE. The flowing of a secretion or excretion.

The DISCHARGE *of electricity between clouds or between a cloud and the earth is known as lightning.*

DISCHARGE

disconformity \ˌdis-kən-'fȯr-mət-ē\ *n.*
EARTH SCIENCE. An area that separates two parallel layers of stratified rock. It is created by the erosion of one layer that is then covered with another layer of rock.

A DISCONFORMITY *represents a lapse of time between the deposition of two layers of rock.*

DISCONFORMITY

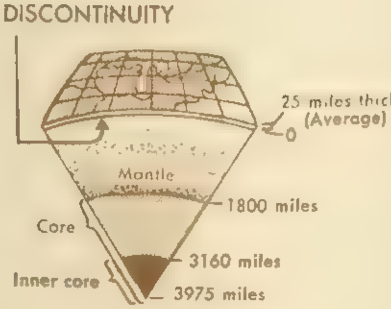
discontinuity \(ˌ)dis-ˌkänt-ᵊn-'(y)ü-ət-ē\ *n.*
EARTH SCIENCE. A sudden or rapid change in structure; also, differences in physical properties between two adjacent areas; also, the area between two air masses of differing temperatures and pressures (a weather front).

The earth's crust is separated from the interior of the earth by a DISCONTINUITY.

discontinuous distribution \ˌdis-kən-'tin-yə-wəs ˌdis-trə-'byü-shən\
BIOLOGY and EARTH SCIENCE. The geographical spread of related organisms in widely-separated regions.

The DISCONTINUOUS DISTRIBUTION *of the tapir, a mammal once native to North America, includes Malaya, Central America and South America.*

DISCONTINUITY



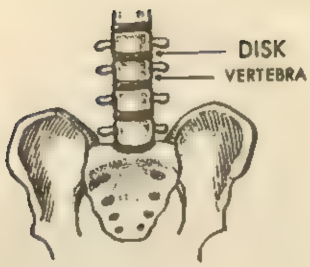
discrete \dis-'krēt\ *adj.*
Referring to distinct or individual parts or to something composed of distinct or individual parts.

When viewed with a microscope, smoke is seen to be composed of DISCRETE *particles.*

disinfectant \ˌdis-ᵊn-'fek-tənt\ *n.*
MEDICINE. A chemical substance that destroys or reduces in number bacteria and viruses capable of causing disease; also, a

substance manufactured for antiseptic use on inanimate objects rather than on living tissue.

Many common household cleaning products now contain both a DISINFECTANT *and a detergent.*



disintegration \(ˈ)dis-ˌint-ə-ˈgrā-shən\ *n.*

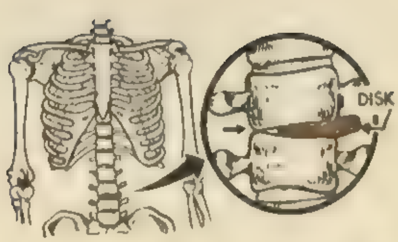
1. PHYSICS. The partial breakdown of a radioactive nucleus by the emission of an alpha or beta particle; also, the total or partial breakdown of nuclei resulting from a collision. 2. The breakdown of a substance into smaller parts.

Atomic DISINTEGRATION *is always accompanied by a release of energy.*

disk \ˈdisk\ *n.*

1. ANATOMY and ZOOLOGY. In animals and human beings, a thin layer of fibrocartilage between each two vertebrae, or bone sections, of the spinal column; also spelled disc. 2. BOTANY. The center of certain composite flowers, surrounded by the corolla or petals; also, any of the cuplike ends on the tendrils of climbing vines that cling to walls and trees; also spelled disc.

The spinal cord runs through each vertebra and each intervertebral DISK.



DISLOCATION

dislocation \ˌdis-(ˌ)lō-ˈkā-shən\ *n.*

MEDICINE. An abnormal change in the position of two bones at a joint; also, the displacement of any part of the body.

A rupture of an intervertebral disk is an example of a DISLOCATION.

dispersal \dis-ˈpər-səl\ *n.*

BIOLOGY. The relocation of plants or animals in a new area; also, the process of reaching a new area.

Seed DISPERSAL *may be caused by wind.*

dispersion \dis-ˈpər-zhən\ *n.*

1. PHYSICS. A separation of the various wavelengths of light; also, the spectrum that results from such separation. 2. CHEMISTRY. The separation of fine particles in a liquid, also, a liquid containing colloidal particles.

A prism causes light DISPERSION *by refracting, or bending, different wavelengths at different angles.*

DISPERSION

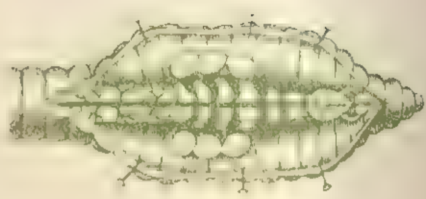
displace \(ˈ)dis-ˈplās\ *v.*

PHYSICS. To push aside or replace one object or substance with another object or substance.

A boat weighing 1,000 pounds must DISPLACE *1,000 pounds of water in order to float.*

dissection \dis-ˈek-shən\ *n.*
BIOLOGY and MEDICINE. The cutting apart or separation of the parts of a plant or an animal in order to study its structure or, in medicine, for diagnosis or treatment of disease; also, a specimen of a part or of a whole organism.

Blunt DISSECTION *is the separation of organs and tissues along their natural cleavage lines rather than directly through their parts.*



DISSECTION
(EARTHWORM)

dissipation \ˌdis-ə-ˈpā-shən\ *n.*
PHYSICS. A loss or transfer of energy from a system or scene of action.

The main function of an automobile engine's cooling system is DISSIPATION *of unwanted heat energy.*

dissociation \(ˌ)dis-ˌō-sē-ˈā-shən\ *n.*
CHEMISTRY. A process by which ions in a crystal are removed from fixed positions and allowed to move freely. The process may be brought about by dissolving or melting a crystal.

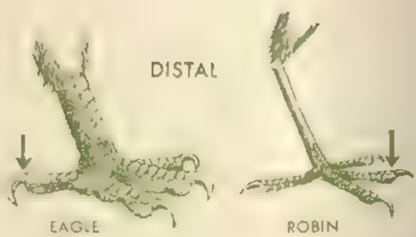
Dissolving or melting table salt results in the DISSOCIATION *of sodium and chloride ions.*

dissolve \diz-ˈälv\ *v.*
CHEMISTRY and PHYSICS. To form a solution.

Water may DISSOLVE *a gas (as air or ammonia), a liquid (as alcohol or glycerin) or a solid (as sugar or salt).*

distal \ˈdist-ᵊl\ *adj.*
ANATOMY and BIOLOGY. Referring to a part, of a plant or animal, located at a distance from the place of attachment or from the center of the body; opposite of proximal.

Some birds have a specially-adapted claw on the DISTAL *end of each toe.*

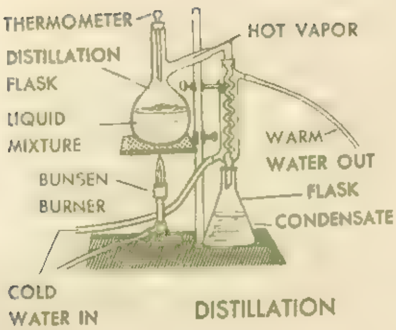


distemper \dis-ˈtem-pər\ *n.*
MEDICINE and ZOOLOGY. A virus disease of dogs, and a number of other mammals, that causes fever, skin eruptions and serious respiratory distress, often ending in pneumonia and frequently fatal; see *panleucopenia.*

Wolves and foxes are two examples of animals that sometimes contract DISTEMPER.

distillate \ˈdis-tə-ˌlāt\ *n.*
CHEMISTRY. A liquid formed or separated as a product of distillation.

A DISTILLATE *is purer than the substance from which it was distilled.*



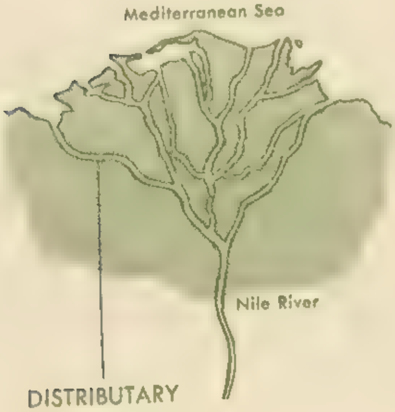
DISTILLATION

distillation \\ˌdis-tə-ˈlā-shən\\ *n.*
CHEMISTRY. A separation of the components of a mixture (or solution) of liquids by heating the mixture until one substance vaporizes and leaves the container as a vapor that may then be condensed.

Crude oil is usually separated from its components by DISTILLATION.

distilled water \\dis-ˈtild ˈwȯt-ər\\
CHEMISTRY. Relatively-pure water collected by boiling water and condensing the steam from it in a separate container.

Because most tap water contains impurities that interfere with chemical reactions, DISTILLED WATER *is used in most chemical analyses.*



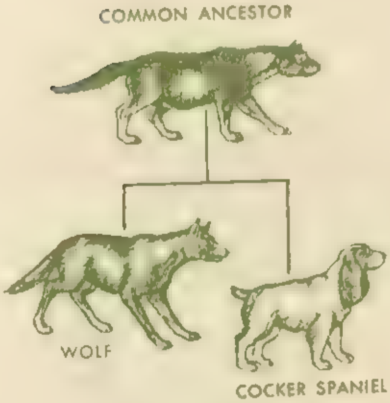
DISTRIBUTARY

distributary \\dis-ˈtrib-yə-ˌter-ē\\ *n.*
EARTH SCIENCE. A stream of water branching off from a river and not returning to it. Distributaries are usually found on deltas and alluvial fans.

Deposition from a DISTRIBUTARY *may produce a fan-shaped river mouth, or delta.*

diurnal \\dī-ˈərn-ᵊl\\ *adj.*
1. ASTRONOMY. Referring to the movement of celestial objects in relation to the earth during a twenty-four-hour period; also, sometimes referring to a period from dawn to dusk. 2. BIOLOGY. Describing the daytime activities of plants and animals, as contrasted with nocturnal. 3. Daily.

The apparent DIURNAL *motion of the celestial sphere is due to the rotation of the earth.*



DIVERGENCE

divergence \\də-ˈvər-jən(t)s\\ *n.*
1. BIOLOGY. The evolutionary development of unlike characteristics in two or more lines of protoplasm that are descended from the same ancestral stock. Divergence occurs as the original type separates, moves into different environments and adapts to them through natural selectivity. 2. PHYSIOLOGY. The spreading out of a nerve impulse after it leaves a cell body.

The coyote, wolf and domesticated dog illustrate DIVERGENCE *from a common ancestor.*

divergent \də-ˈvər-jənt\ *adj*

[illegible] terms do not converge to a limiting value.

[illegible] consecutive terms of the sequence are −1 and 1.

diverging lens \də-ˈvər-jiŋ ˈlenz\

[illegible]

[illegible] over a large area.

diverticulum [illegible] *n*

[illegible]

A diverticulum of the colon may be caused by [illegible]

divide \də-ˈvīd\

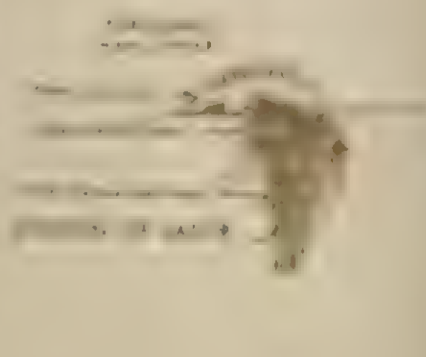
[illegible] and a division.

[illegible]

division of labor [illegible]

[illegible]

[illegible]



divisor \də-ˈvī-zər\ *n*

MATHEMATICS The [illegible] the dividend [illegible]

In the expression 12 ÷ 2, the divisor is 2.

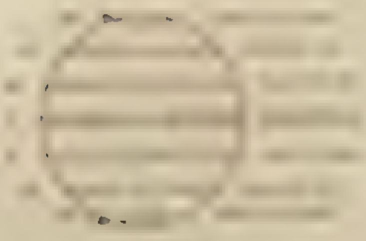
DNA

[illegible]

doldrums [illegible]

[illegible] called the doldrum belt and the equatorial belt

A trade wind belt lies on either side of the [illegible]



[illegible]

dolomite [illegible]

[illegible] $CaMg(CO_3)_2$, occurring in crystalline [illegible]

[illegible]

domain [illegible]

[illegible]

dome [illegible]

[illegible]

dominance principle [illegible]

[illegible]

dominant trait [illegible]

[illegible]

Doppler effect \'däp-lər i-'fekt\
PHYSICS. An increase or decrease in the frequency of sound or light waves that is caused by relative motion between the source of the wave and the observer.

An observer who hears a train whistle become higher in pitch as a train approaches and lower in pitch as it departs experiences the DOPPLER EFFECT.

SAILFISH

Doppler shift \'däp-lər 'shift\
ASTRONOMY. A slight moving over of the lines in the spectra produced by some celestial bodies. The shift is an example of the Doppler effect.

The DOPPLER SHIFT *in the spectra of approaching stars is toward the violet end of the spectrum.*

dormant \'dȯr-mənt\ *adj.*
BIOLOGY and EARTH SCIENCE. Resting; not active, as a seed or an animal in hibernation; inactive, as a volcano.

Tulip bulbs remain DORMANT *from late summer through the winter but become active and sprout early in the spring.*


DORSIVENTRAL

dorsal \'dȯr-səl\ *adj.*
1. ANATOMY and ZOOLOGY. Referring to the back or the area near the back of an animal; opposite of ventral. 2. BOTANY. Referring to the upper surface of certain plants that do not have clearly-defined roots, stems or leaves, such as algae.

The sailfish takes its name from its large, saillike DORSAL *fin.*

dorsiventral \,dȯr-si-'ven-trəl\ *adj.*
1. ZOOLOGY. Describing a part of an animal that extends from the back to the front. 2. BOTANY. Describing a part of a plant, such as a leaf, having upper and lower surfaces distinctly different.

The DORSIVENTRAL *line on each side of a fish is believed to contain special sensory organs used in the detection of low-frequency vibrations in the water.*


DOSIMETER
(POCKET)

dosimeter \dō-'sim-ət-ər\ *n.*
MEDICINE and PHYSICS. A device used to measure the quantity of X-ray and other ionizing radiation to which an organism is exposed in a given time; a quantimeter.

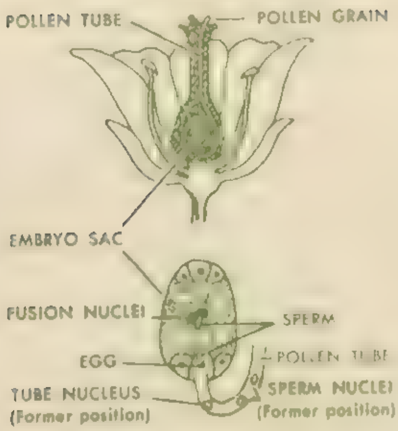
Because a typical DOSIMETER *is similar in size and shape to a fountain pen, it is often called a pen meter, or pocket meter.*

double bond \\'dəb-əl 'bänd\\

CHEMISTRY. A joining or linking of two atoms in a molecule, occurring when the two atoms share two pairs of electrons; often symbolized in structural formulas by two parallel dashes (=).

A DOUBLE BOND *occurs in an ethylene molecule, as shown by its structural formula, $H_2C = CH_2$.*

DOUBLE FERTILIZATION



double fertilization \\'dəb-əl ˌfərt-ᵊl-ə-'zā-shən\\

BOTANY. Fertilization in seed plants that involves fusion between a sperm nucleus and an egg nucleus, resulting in an embryo, and fusion between a second sperm nucleus and two separate or fused polar nuclei, resulting in endosperm.

In the pepper plant, when a pollen tube enters an embryo sac, one sperm fertilizes the egg while the other sperm unites with the fusion nuclei, bringing about a DOUBLE FERTILIZATION.

double refraction \\'dəb-əl ri-'frak-shən\\

PHYSICS. The splitting of a light beam by crystals, resulting in two separate light rays.

Calcite, or Iceland spar, is a crystal that shows DOUBLE REFRACTION.

double replacement \\'dəb-əl ri-'plā-smənt\\

CHEMISTRY. A chemical reaction between two compounds to form two different compounds; a reaction in which one or more atoms, ions or radicals in one compound change places with one or more atoms, ions or radicals in a second compound; also called metathesis.

Solutions of sodium chloride and silver nitrate undergo a DOUBLE REPLACEMENT *reaction to form undissolved silver chloride and soluble sodium nitrate.*

DOUBLE STARS

double salt \\'dəb-əl 'sȯlt\\

CHEMISTRY. A salt, such as an alum that forms two different positive ions or negative ions when reacting with water (hydrolysis); also, a salt that is a combination of two different salts.

An important ingredient of some baking powders is the DOUBLE SALT, *alum, whose chemical formula is $NaAl(SO_4)_2$.*

double stars \\'dəb-əl 'stärz\\

ASTRONOMY. Two stars in the same line of vision that appear as one star unless viewed through a telescope; also, binary stars; see *binary stars.*

DOUBLE STARS *in the same line of vision but not revolving around each other are called optical binaries.*